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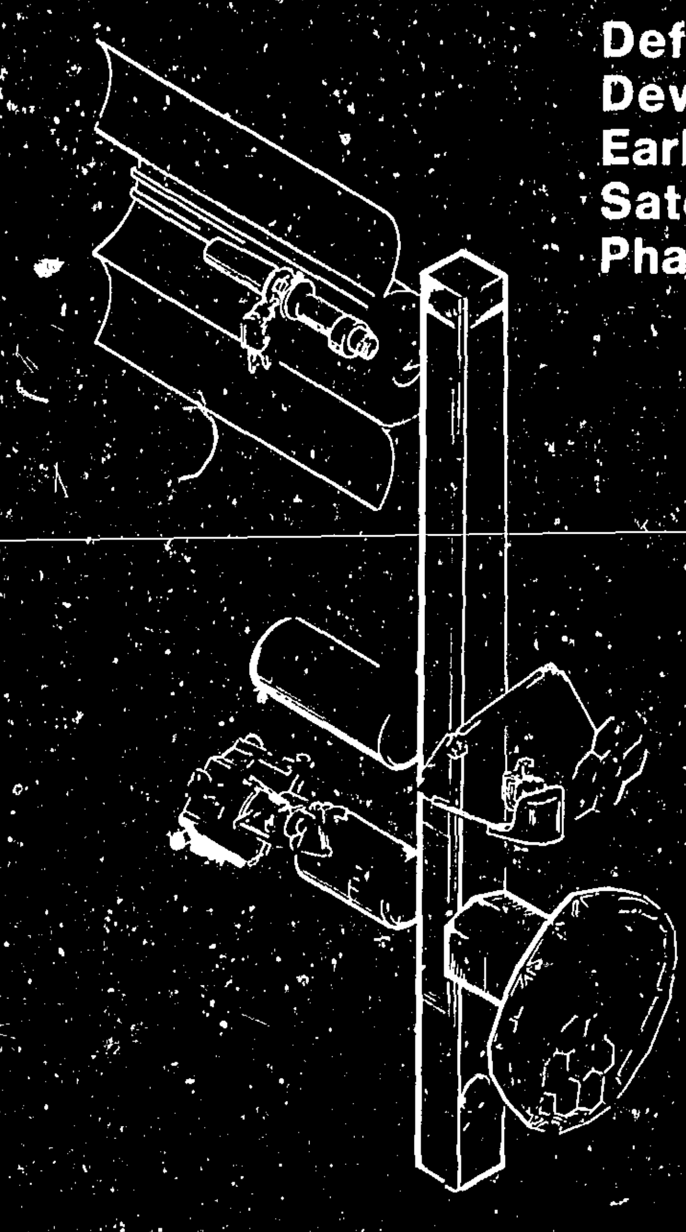
# Definition of Technology Development Missions for Early Space Station Satellite Servicing Phase 2—Final Report



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# DEFINITION OF TECHNOLOGY DEVELOPMENT MISSIONS FOR EARLY SPACE STATION SATELLITE SERVICING PHASE 2—FINAL REPORT

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## FOREWORD

This final report, submitted to National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), presents the results of the Definition of Technology Development Missions for Early Space Station - Satellite Servicing performed by Martin Marietta Aerospace under NASA Contract NAS8-35042.

CONTENTS

FIGURES (continued)

ACRONYMS

| | |
|---|---|
| AI | Artificial Intelligence |
| AXAF | Advanced X-Ray Astrophysics Facility |
| CCTV | Closed Circuit Television |
| C&DH | Communications and Data Handling |
| CDR | Critical Design Review |
| CER | Cost Estimating Relationships |
| CSCP | Communication System Control Processor |
| DDT&E | Design, Development, Test and Evaluation |
| DOD | Department of Defense |
| ECLSS | Environmental Control/Life Support System |
| EMU | Extravehicular Mobility Unit |
| EOS | Electrophoresis Operations in Space |
| EVA | Extravehicular Activity |
| GD | General Dynamics |
| GDA | General Dynamics Aerospace |
| GEO | Geosynchronous Earth Orbit |
| GFE | Government Furnished Equipment |
| GN&C | Guidance Navigation and Control |
| GPS | Global Positioning System |
| GRO | Gamma Ray Observatory |
| HEC | High Energy Change |
| HEO | High Earth Orbit |
| HRDS | High Resolution Dispersive Spectrometer |
| IOC | Initial Operational Capability |
| IOSS | Integrated Orbital Servicing System |
| IRD | Independent Research and Development |
| IS | Intelligent Servicer |
| IVA | Intravehicular Activity |
| LDR | Large Deployable Reflector |
| LEC | Low Energy Change |
| LEO | Low Earth Orbit |
| LeRC | Lewis Research Center |
| LOS | Line of Sight |
| LRI | Low Resolution Imager |
| LRS | Low Resolution Spectrometer |
| LRU | Lowest Replaceable Unit |
| LVLH | Local Vertical Local Horizontal |
| MDAC | McDonnell Douglas Astronautics Corporation |
| MFR | Manipulator Foot Restraint |
| MMC | Martin Marietta Corporation |
| MMS | Multi-mission Modular Spacecraft |
| MMU | Manned Maneuvering Unit |
| MPP | Materials Processing Platform |
| MPS | Materials Processing Systems |
| MRR | Maintenance Repair and Retrofit |
| MRS | Moderate Resolution Spectrometer |
| MSFC | Marshall Space Flight Center |

| | |
|---|---|
| NA | Not Applicable |
| NASA | National Aeronautics and Space Administration |
| OMV | Orbital Maneuvering Vehicle |
| ORU | Orbital Replacement Unit |
| OTV | Orbital Transfer Vehicle |
| PDP | Plasma Diagnostics Package |
| PDR | Preliminary Design Review |
| P/L | Payload |
| PMD | Propellant Management Device |
| POCC | Payload Operations Control Center |
| PRC | Planning Research Center |
| PTS | Propellant Transfer System |
| QD | Quick Disconnect |
| RCS | Reaction Control System |
| RF | Radio Frequency |
| RMS | Remote Manipulator System |
| ROM | Relative Order of Magnitude |
| S/C | Spacecraft |
| SDR | Software Design Review |
| SFMD | Storable Fluid Management Demonstration |
| SFRMS | Servicing Facility Remote Manipulator System |
| SMRM | Solar Maximum Repair Mission |
| SOW | Statement of Work |
| SPAS | Shuttle Pallet Satellite (German) |
| SRA | Systems Requirements Analysis |
| SS | Space Station |
| SSGC | Space Station Ground Control |
| SSMC | Space Station Mission Control |
| SSMCC | Space Station Mission Control Center |
| SSRMS | Space Station Remote Manipulator System |
| ST | Space Telescope |
| STS | Space Transportation System |
| TD&FE | Technology Development and Flight Experiment |
| TDM | Technology Development Mission |
| TDRS | Tracking and Data Relay Satellite |
| TDRSS | Tracking and Data Relay Satellite System |
| TMS | Teleoperated Maneuvering System |
| UARS | Upper Atmosphere Research Satellite |
| XGP | Experimental Geostationary Platform |
| 3-D | Three Dimension |

## 1.0 INTRODUCTION AND SUMMARY

### 1.1 Purpose

The purpose of Phase 2 of the Satelite Servicing Study was to expand and refine the overall understanding of how best to use the manned Space Station as a test bed for demonstration of satellite servicing capabilities. By selecting five specific, high priority Technology Development Missions (TDM), and conducting functional and operational analyses on the TDMs, servicing requirements for Space Station components and support equipment were to be refined and clarified. Specifically, the purpose of Phase 2 was to improve the definition of accommodation requirements necessary to support servicing missions, to develop an integrated Technology Development and Flight Experiment Plan, to outline a time-phased schedule for ground development and onorbit/validation of technology required for servicing at Space Station. This study was to build on the results of the Phase 1 satellite servicing contract.

### 1.2 Ground Rules and Guidelines

The following ground rules and guidelines were used as the basis of analyses in the performance of this study.

a. Use applicable data and results from previous and current studies;

b. Use the STS as the delivery vehicle for servicing elements needed at the Space Station for conduct of TDMs;

c. An early Space Station is to be operational in 1991;

d. The OMV will be available to support onorbit operations;

e. Cost estimates for technology development and TDM implementation is to be supported by ground rules and assumptions;

f. The STS will be available for appropriate early TDM precursor activities.

These ground rules and guidelines were followed in all aspects of Phase 2 study activities.

## 1.3 Scope

This Technical Report is a description of the second phase of the MSFC study, Definition of Technology Development Missions for Early Space Station Satellite Servicing. Phase 1 was conducted during October, 1982 through May, 1983. A technical report for Phase 1 was provided to MSFC in May 1983. The Phase 2 servicing study was initiated in June 1983, and is being reported in this document. The scope of the contract was to: 1) define in detail five selected Technology Development Missions (TDM); 2) conduct a design requirements analysis to refine definitions of satellite servicing requirements at the Space Station, and 3) develop a technology plan that would identify and schedule prerequisite precursor technology development, associated STS flight experiments and Space Station flight experiments needed to provide onorbit validation of the evolving technology.

The Phase 2 study results are presented in two volumes: Volume I, Executive Summary - Phase 1 & Phase 2; and this volume - Volume II, Technical Volume - Phase 2.

Appendix A, contains - Common Activity Sequence Tables

## 1.4 Approach

The approach used in conducting the Phase 2 satellite servicing study is shown in Figure 1.4-1.

### 1.4.1 TDM Selection

TDM Selection was the first step in the study process and was supported by the work accomplished by all four Phase 1 contracts. Using all of the TDMs identified by the four contractors, selection criteria were devised and each of the TDMs were evaluated to rank order them with regard to value added to servicing at the Space Station. The selected TDMs were reviewed with NASA/MSFC to secure their concurrence.

### 1.4.2 TDM Detailed Definition

The detailed definition of selected TDMs was supported by a number of previous STS and Space Station-related studies. Studies and reports on the specific satellites selected for TDM definition such as the Advanced X-Ray Astrophysics Facility (AXAF), Electrophoresis Operations in Space (EOS) and the Large Deployable Reflector (LDR), were reviewed and provided excellent support to this study. The detailed definition of selected TDMs included several activity phases. First, the mission scenario for each TDM was defined. Alternative action sequences were considered and marginal approaches were deleted. With TDMs defined, functional analyses were conducted to determine servicing requirements and to identify technology development, "new start", requirements. Requirement data bases were established for derived requirements and technology development requirements. Operational analyses were conducted next to ascertain the need for multiple elements such as EMUs and MMUs, as many activities were accomplished in parallel. The results of TDM detailed definition served as inputs to all other tasks. This major task was structured and conducted from the beginning with this objective in mind.

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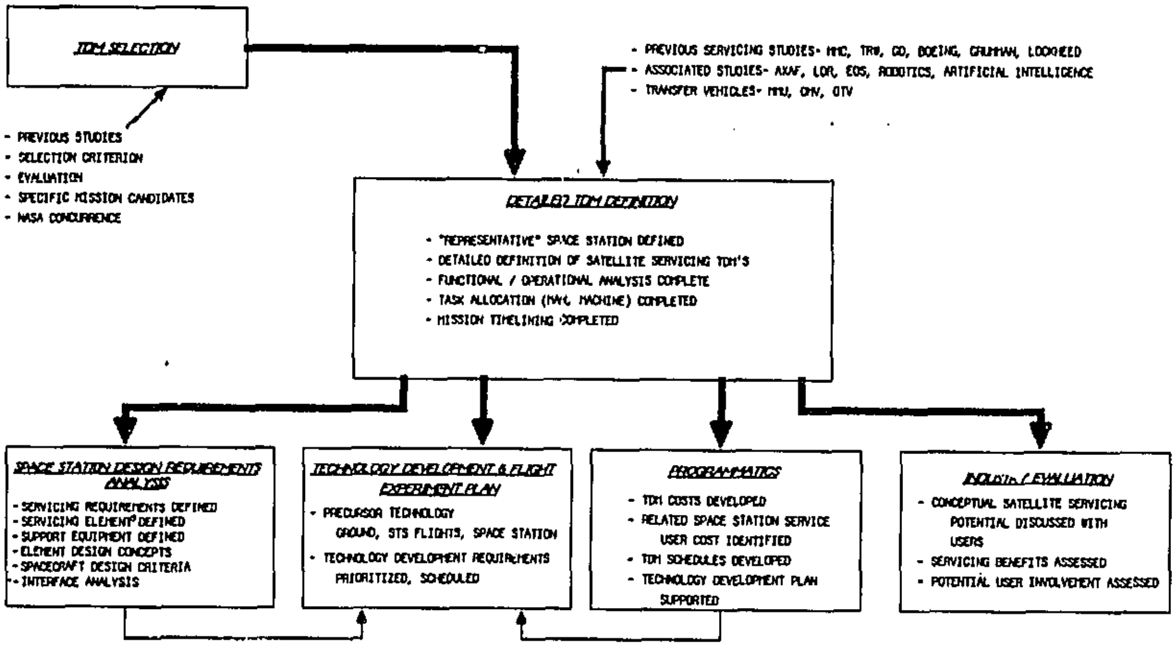



*Figure 1.4-1 Satellite Servicing Study Flow*

### 1.4.3 Design Requirements Analysis

The next sequential study task was to conduct a Design Requirements Analysis, an analysis of Space Station design requirements for satellite servicing. The resulting data was intended to support design of service support equipment capable of supporting TDM servicing demonstrations. The results of the design requirements analysis task were: 1) definition of service requirements, support to the definition of Space Station, and definition of the specific servicing accommodation needs, including servicing hangars, storage hangars and fuel depots; 2) definition of support equipment (Space Station RMS, carousel mechanisms, servicing equipment consoles); 3) some conceptual designs of servicing elements and support equipment; 4) a top level definition of satellite design criteria for servicing at Space Station; and 5) a detailed evaluation of requisite servicing interfaces.

### 1.4.4 Technology Development and Flight Experiment Plan

Generation of the Technology Development and Flight Experiment Plan was supported strongly and directly by identification of servicing precursor technology development in Design Requirements Analysis. This precursor technology included basic technology development in areas such as fluid transfer management, ground controlled/teleoperated docking (for OMV/OTV), aero-assist braking (aerobrake) for OTV, development of techniques and tools for onorbit assembly of adaptive mirror segments, and a wide range of servicing-related automation advances. The Plan also outlines those onorbit activities, both on STS and at the Space Station, needed to provide zero-gravity verification of appropriate technology development advances, such as cryogenic fluid transfer devices.

### 1.4.5 Programmatic Analysis

The programmatic portion of the study was directly supported by TDM Detailed Definition. The task included development of TDM schedules and costs. Costing ground rules were specified for costing of each TDM. This was essential as the TDMs were significantly different. For each TDM, costs were presented in three categories; 1) Space Station specific costs; 2) user specific costs; and 3) unique costs directly related to the TDM demonstration activities. One of the conclusions produced by this approach was to validate the assertion that TDM costs could be reduced by sharing their costs with prospective users.

### 1.4.6 Commercial Satellite Servicing Assessment

The approach used to complete the final task, Industry Evaluation of satellite servicing at the Space Station, was to call and visit potential commercial space users to brief them on the anticipated servicing capabilities at the early Space Station and provide a projection of capabilities at a mature Space Station. These discussions provided insights on planning for servicing both at the STS and subsequently at Space Station. The industrial firms included in this survey provided valuable viewpoints related to the need for specific information to assist them in planning for servicing at or from the Space Station.

## 2.0 TECHNOLOGY DEVELOPMENT MISSION (TDM) DETAILED DEFINITION

The TDM Detailed Definition task was performed in two sequential steps. The first sub-task was to consider appropriate candidate servicing scenarios, to select the five highest priority missions, and to secure NASA Marshall Space Flight Center (MSFC) approval of the five for detailed definition.

Following MSFC approval of the TDM selections, a detailed definition of each was conducted. The technology development missions (TDMs) were designed to demonstrate a specific satellite servicing capability or set of capabilities conducted at or initiated from the Space Station. The detailed definitions of Martin Marietta's approved TDMs included: description and scope of servicing demonstration(s) provided; functional and operational analyses, activity sequence(s) of missions; identification of required precursor activities; and specific issues related to the TDM. TDM Detailed Definition was the principal study task, with fifty percent of the study effort dedicated to it.

### 2.1 TDM Selection Process

The approach used in technology development mission selection was to build on the results of the Satellite Servicing Phase 1 study results and other related studies. The methodology was straight forward and effective, and subsequent comparison of these TDMs with evolving Space Station Mission Models has validated the high priorities given to these missions. The selection process is summarized in Figure 2.1-1.

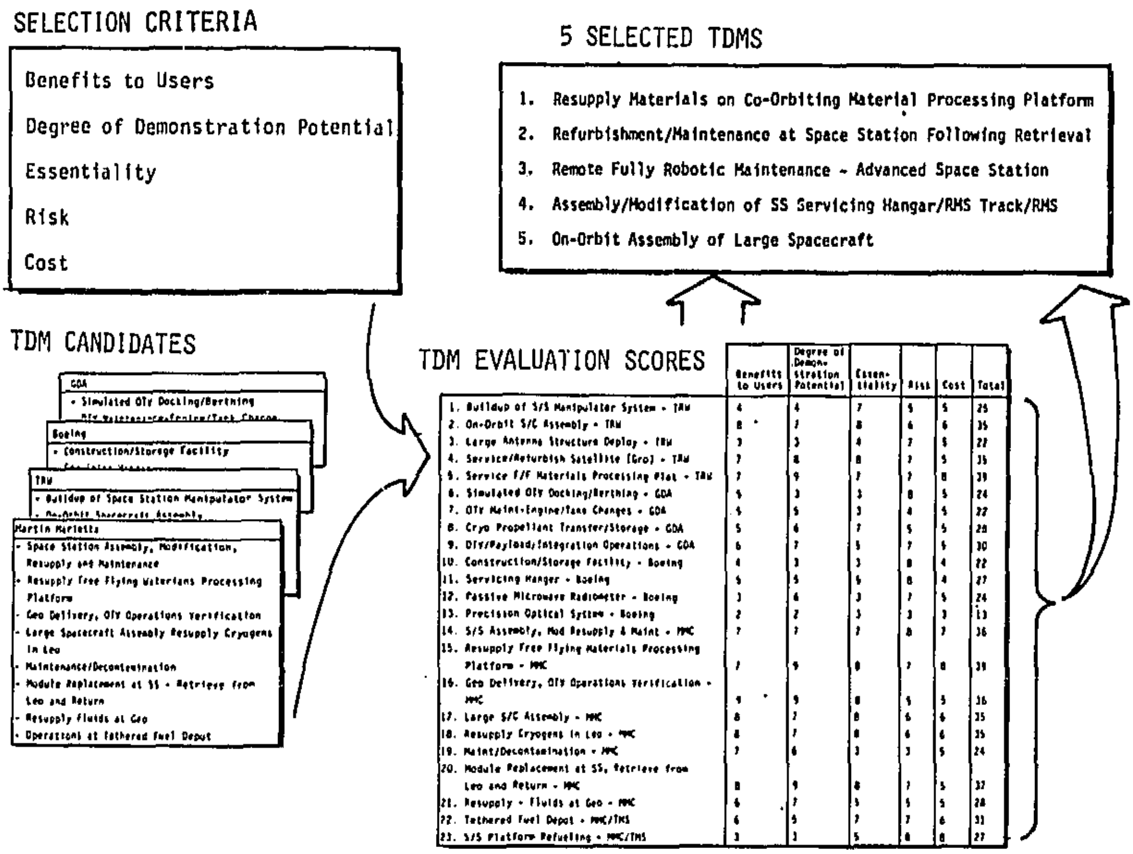
#### 2.1.1 TDM Selection Criteria

The study team evaluated a number of selection criteria and agreed on five definitive standards of judgment. The key attributes of the five selection criteria are shown in Table 2.1.1-1, and are shown in priority rank order. Benefits to users was considered highest in potential value, thus, servicing TDMs that extend life and provide enhanced capability, such as retrofit of upgraded technology, were highly rated.

Degree of demonstration potential, was also weighted high as a servicing criterion, and TDMs demonstrating more than one servicing capability also received high value. Martin Marietta established a goal of demonstrating high fidelity servicing missions to provide confidence to potential users. Thus, missions providing a high degree of realism were rated high.

A third criterion, essentiality, related to how often the service would be required and used, and how critical, this particular servicing capability would be considered, by either NASA or DOD.

Cost and risk were the final selection criteria with high risk and cost considered negative factors in our rating methodology.




| | Benefits to Users | Degree of Demonstration Potential | Essentiality | Risk | Cost | Total |
|---|---|---|---|---|---|---|
| 1. Buildup of S/S Manipulator System - TRW | 4 | 4 | 7 | 5 | 5 | 25 |
| 2. On-Orbit S/C Assembly - TRW | 8 | 7 | 8 | 6 | 6 | 35 |
| 3. Large Antenna Structure Deploy - TRW | 3 | 3 | 4 | 7 | 5 | 22 |
| 4. Service/Refurbish Satellite (Gro) - TRW | 7 | 8 | 8 | 7 | 5 | 35 |
| 5. Service F/F Materials Processing Plat - TRW | 7 | 9 | 7 | 7 | 8 | 39 |
| 6. Simulated OTV Docking/Berthing - GDA | 5 | 3 | 3 | 8 | 5 | 24 |
| 7. OTV Maint-Engine/Tank Changes - GDA | 5 | 5 | 3 | 4 | 5 | 22 |
| 8. Cryo Propellant Transfer/Storage - GDA | 5 | 6 | 7 | 5 | 5 | 28 |
| 9. OTV/Payload/Integration Operations - GDA | 6 | 7 | 5 | 7 | 5 | 30 |
| 10. Construction/Storage Facility - Boeing | 4 | 3 | 3 | 8 | 4 | 22 |
| 11. Servicing Hanger - Boeing | 5 | 5 | 5 | 8 | 4 | 27 |
| 12. Passive Microwave Radiometer - Boeing | 3 | 6 | 3 | 7 | 5 | 24 |
| 13. Precision Optical System - Boeing | 2 | 2 | 3 | 3 | 3 | 13 |
| 14. S/S Assembly, Mod Resupply & Maint - MMC | 7 | 7 | 7 | 8 | 7 | 36 |
| 15. Resupply Free Flying Materials Processing Platform - MMC | 7 | 9 | 8 | 7 | 8 | 39 |
| 16. Geo Delivery, OTV Operations Verification - MMC | 9 | 9 | 8 | 5 | 5 | 36 |
| 17. Large S/C Assembly - MMC | 8 | 7 | 8 | 6 | 6 | 35 |
| 18. Resupply Cryogens in Leo - MMC | 8 | 7 | 8 | 6 | 6 | 35 |
| 19. Maint/Decontamination - MMC | 7 | 6 | 3 | 3 | 5 | 24 |
| 20. Module Replacement at SS, Retrieve from Leo and Return - MMC | 8 | 9 | 8 | 7 | 5 | 37 |
| 21. Resupply - Fluids at Geo - MMC | 6 | 7 | 5 | 5 | 5 | 28 |
| 22. Tethered Fuel Depot - MMC/TMS | 6 | 5 | 7 | 7 | 6 | 31 |
| 23. S/S Platform Refueling - MMC/TMS | 3 | 3 | 5 | 8 | 8 | 27 |

*Figure 2.1-1* *TDM Selection Process*

*Table 2.1.1-1* *TDM Selection Criteria*

- BENEFITS TO USER
  - COST SAVINGS
  - EXTENDED PAYLOAD LIFE - COST AVOIDANCE OF NEW LAUNCH/NEW SPACECRAFT
  - ENHANCED CAPABILITY - REPLACING OLD ORU WITH NEW TECHNOLOGY SYSTEM
- DEGREE OF DEMONSTRATION POTENTIAL
  - DEMONSTRATE MISSION LEVEL OPERATIONAL SERVICING CAPABILITY
  - SERVICING FIDELITY, MISSION REALISM
  - SERVICING CONFIDENCE LEVEL ENHANCED
- ESSENTIALITY
  - FREQUENCY OF SERVICING REQUIREMENT
  - CRITICALITY OF SERVICING
  - AVAILABLE ALTERNATIVES - ANY OTHER WAY
- RISK
  - TECHNOLOGICAL - CRITICAL TECHNOLOGY DEVELOPMENT UNDERWAY/PLANNED
  - SERVICE OPPORTUNITIES - FREQUENT, RATE (ORBITAL PHASING PROBLEMS)
  - SAFETY - SPACE STATION SYSTEMS, USER SATELLITES
- COST
  - TOTAL COST (HIGH, LOW)
  - COST OF SPACE STATION ACCOMMODATION NEEDS

### 2.1.2 TDM Candidates

TDM candidates included all those presented by the Phase 1 study contractors; Martin Marietta, TRW, Boeing, and General Dynamics Astronautics (GDA). These are shown on Table 2.1.2-1.

Also included were a number of specific servicing scenarios receiving some degree of interest at that point in time, such as "operations at a tethered fuel depot."

These candidate TDMs, 23 in number, were individually evaluated by a number of personnel with extensive Space Station and satellite servicing experience, and each TDM rating factor was normalized across all evaluators. The resulting scores were compared, and the top five demonstration scenarios were selected.

Note that these missions are described in a generic sense. They were described in this sense for the specific purpose of ensuring selection based on the asserted highest priority criteria, benefits to users and degree of demonstration potential.

Note that, as shown in the right hand column of Table 2.1.2-2, the selected five TDMs cover most aspects of all but six of the 23 candidate TDMs. With this selection, most of these crucial servicing scenarios are represented in the five TDMs selected for detailed definition.

### 2.1.3 Specific TDM Selection

With a generic set of servicing "demonstration mission" scenarios prioritized and selected, the second phase of "TDM Selection" was conducted by Martin Marietta. This specific TDM selection activity was mandated by the study team's conviction that definition of TDMs using actual operational satellites or planned systems would offer the following distinct advantages:

a. A more precise, less abstract mission, enables refined definitions of Space Station accommodation needs.

b. The use of defined satellite/spacecraft systems, with evolving RMS, MMU, EVA, OMV, and OTV systems, would add fidelity to TDM mission concepts.

c. The concept of sharing TDM costs with potential users, to demonstrate servicing capabilities at the Space Station, is viable, and with funding limitations, could be a compelling consideration.

Each of the generic TDM candidates were evaluated next, to determine the most viable, high fidelity servicing mission for detailed definition. An outline of this expanded TDM selection is shown in Table 2.1.3-1.

*Table 2.1.2-1 TDM Candidates*

- TRW
  - BUILD UP OF SPACE STATION MANIPULATOR SYSTEM
  - ON-ORBIT SPACECRAFT ASSEMBLY
  - LARGE ANTENNA STRUCTURE/DEPLOY
  - SERVICE/REFURBISH SATELLITE (GRO)
  - SERVICE FREE/FLYING MATERIALS PROCESSING PLATFORM
- GDA
  - SIMULATED OTV DOCKING/BERTHING
  - OTV MAINTENANCE-ENGINE/TANK CHANGE
  - CRYOGEN PROPELLANT STORAGE/ TRANSFER
  - OTV/PAYLOAD INTEGRATION OPERATIONS
- BOEING
  - CONSTRUCTION/STORAGE FACILITY
  - SERVICING HANGAR
  - PASSIVE MICROWAVE RADIOMETER
  - PRECISION OPTICAL SYSTEM
- MARTIN MARIETTA
  - SPACE STATION ASSEMBLY, MODIFICATION, RESUPPLY AND MAINTENANCE
  - RESUPPLY FREE FLYING MATERIALS PROCESSING PLATFORM
  - GEO DELIVERY, OTV OPERATIONS VERIF.
  - LARGE SPACECRAFT ASSEMBLY
  - RESUPPLY CRYOGENS IN LEO
  - MAINTENANCE/DECONTAMINATION
  - MODULE REPLACEMENT AT SS - RETRIEVE FROM LEO AND RETURN
  - RESUPPLY FLUIDS AT GEO
  - OPERATIONS AT TETHERED FUEL DEPOT
  - SPACE STATION PLATFORM REFUELING

*Table 2.1.2-2 Selected TDM's*

| TDM \ SELECTION CRITERIA | BENEFIT TO USERS | DEGREE OF DEMONSTRATION POTENTIAL | ESSENTIALITY | RISK | COST | TOTAL | CANDIDATE TDMS INCLUDED |
|---|---|---|---|---|---|---|---|
| RESUPPLY FREE FLYING MATERIALS PROCESSING PLATFORM/TRANSFER RETURN | 8 | 8 | 8 | 7 | 8 | 39 | 1,5,10,11, 14,15,21, 22,23 |
| REFURBISH/MAINTENANCE AT S/S, RETRIEVE FROM LEO TO SS AND RETURN | 8 | 9 | 8 | 7 | 5 | 37 | 1,4,10,11, 14,20,22 |
| SPACECRAFT DELIVERY TO GEO/ REUSABLE OTV OPERATIONS VALIDATION | 9 | 9 | 8 | 5 | 5 | 36 | 1,6,7,8,9, 10,11,14, 16,22 |
| SS ASSEMBLY/MODIFICATION OF SERVICE HANGAR/TRACK/RMS | 7 | 7 | 7 | 8 | 7 | 36 | 1,10,11 |
| ON-ORBIT ASSEMBLY OF LARGE SPACECRAFT | 8 | 7 | 8 | 6 | 6 | 35 | 1,2,10,11, 14,17,* |

*ADD OTHER TDMs PROVIDING LEO OR GEO DELIVERY CAPABILITY.

*Table 2.1.3-1 Specific TDM Selection Rationale*

TDM 1 - RESUPPLY MATERIALS PROCESSING PLATFORM

- REAL MATERIALS PROCESSING CANDIDATE SELECTED
    - ELECTROPHORESIS OPERATIONS IN SPACE (EOS) SELECTED
    - EXAMINED MANY INCLUDING ELECTROEPITAXIAL GROWTH OF GALIUM ARSENITE CRYSTALS, IRON PROCESSING

TDM 2 - RETRIEVE/REPAIR SPACECRAFT AT SPACE STATION

- OMV CAPABILITY AT IOC (NO REPAIR KITS) SCOPE OF MOST REPAIR MISSIONS MANDATES REPAIR AT SPACE STATION
- EVALUATED ST, GRO, UARS, AXAF
- SPACE STATION SERVICING EVOLUTION FAVORS AXAF-1ST REPAIR IN 1993-4
- AXAF MISSION WELL DEFINED, EXTENSIVELY DESIGNED FOR SERVICING
- ENABLES CONSIDERATION OF MODULE REPLACEMENT, FLUID TRANSFER, SOLAR ARRAY REPLACEMENT/REFURBISHMENT

TDM 3 - ASSEMBLY/MODIFICATION OF SPACE STATION

- WE CHOSE MODIFICATION, SELECTED TASK OF ADDING SERVICING AREA TO SPACE STATION
- BENEFITS ARE: INCREASED UNDERSTANDING OF SERVICE ELEMENTS, MORE REFINED SUPPORT EQUIPMENT DERIVATION, ASSEMBLY CONCEPTS

TDM 4 - ONORBIT ASSEMBLY OF LARGE SPACECRAFT

- EVALUATED SEVERAL CANDIDATES
    - LARGE DEPLOYABLE ANTENNA (LDA)
    - DEPLOYABLE SOLAR ARRAY (DSA)
    - LARGE DEPLOYABLE REFLECTOR (LDR)
- SELECTED LDR - BEST DEFINED AT THAT TIME

TDM 5 - REMOTE REPAIR BY INTELLIGENT SERVICER

- REQUESTED BY MSFC TO DEFINE AN ADVANCED AUTOMATION TDM DEMONSTRATING FAR TERM SERVICING CAPABILITY AT SPACE STATION
- SELECTED SATELLITE REPAIR AT GEO USING INTELLIGENT SERVICER DEMONSTRATING AUTOMATION ADVANCES

For TDM 1, the resupply of a Free-Flying Materials Processing Platform (MPP), a realistic materials processing candidate was selected. Many space processing programs were examined, including electroepitaxial growth of galium arsenite crystals and cast iron processing, but the Electrophoresis Operations in Space (EOS) program appeared to offer the most realistic candidate at the time. Subsequent history has validated this selection as the EOS program recently completed its fifth STS flight experiment with excellent results. As will be shown later in the study, EOS program directors today are counting heavily on eventual Space Station capability and expect to have a number of processing platforms operating during the early Space Station period.

TDM 2, retrieval and repair of an operating spacecraft at the Space Station, appears to be a high priority early servicing candidate because the initial Orbital Maneuvering Vehicle (OMV) is not expected to have remote servicing capability; i.e., no intelligent front end remote servicing kit. Thus, most early Space Station servicing will be done at the Space Station. Several real world candidates were considered, including Space Telescope (ST), Gamma Ray Observatory (GRO), Upper Atmosphere Research Satellite (UARS), and the Advanced X-Ray Astrophysics Facility (AXAF). The Space Station servicing growth rate appeared to favor selection of AXAF, which has a planned repair mission in 1993-94. The AXAF mission is well defined and AXAF is extensively designed for onorbit servicing. The use of AXAF allowed consideration of servicing tasks such as module replacement, fluid transfer, and solar array and antenna refurbishment or replacement.

The third TDM demonstrates one of three servicing categories of interest initially outlined by MSFC during Phase 1 and continued during the Phase 2 contract. The three categories were: 1) Space Station Assembly/Modification; 2) Large Spacecraft Assembly Onorbit; and 3) servicing and repair of satellites at the Space Station. This TDM demonstrates Space Station modification capability. The TDM selected was assembly of the satellite servicing support area, as this type of mission would add clarity to the definition of specific servicing elements and support equipment required for servicing at the Space Station. This objective was clearly achieved.

The objective of TDM 4, large spacecraft assembly, was to examine the second major MSFC area of servicing interest. The assembly of the Large Deployable Reflector (LDR) was chosen for two reasons. First, the project was the best defined of those considered, with many related studies available, including some consideration of the assembly problems associated with this mission. Secondly, it is an extremely challenging onorbit assembly sequence, and definition of this assembly process would add clarity to the identification of Space Station accommodation needs.

The fifth and final TDM was a stimulating, technical challenge. MSFC requested that Martin Marietta not define a satellite delivery to GEO, a scenario that received a high rating, but instead explore the possibilities offered by space automation to define a servicing scenario for the late 1990s. MSFC wanted to demonstrate servicing opportunities potentially available at an evolving, mature Space Station. Using the results of an internal independent research and development (IR&D) effort already underway as a starting point, TDM 5 was developed. This

technology development mission was designed to illustrate the capability of an advanced technology servicer to conduct nearly autonomous operations, under human "supervisory control", at a disabled satellite in synchronous orbit.

These were the five TDMs approved by NASA MSFC for detailed definition in the Phase 2 portion of the satellite servicing contract.

## 2.2 TDM Detailed Definition

The TDM definition task was interpreted by Martin Marietta to include a thorough description of the mission and the servicing capabilities to be demonstrated by each TDM. The sequence of events for each was outlined to display the results of functional and operational analyses.

The event sequencing included a breakout of pre-mission activities, direct TDM mission activities, and post-mission activities. Pre-mission activities were defined as activities directly related to conduct of the mission, but not labeled as precursor activities. These will be defined subsequently. Mission activities were those activities included directly in the actual conduct of the servicing demonstration. Post-mission activities were those activities, following completion of the mission, that would be required to ensure continued orderly Space Station operation such as; cleanup operations; and return to earth of TDM residuals, i.e., processed modules, specific TDM equipment, tools, etc.

The TDM event sequencing included a description of servicing activities, crew involvement, support equipment required, event time and elapsed times.

For each TDM, servicing requirements derived from the functional and operational analyses, were collected as input to the Design Requirements Analysis Task.

In addition, all precursor activities including; 1) basic technology development requirements (technology startups, accelerations); 2) STS flight experiments required to support onorbit or zero-gravity validation of the appropriated technology development; and 3) Space Station validations of equipment and operations concepts for conduct of each of the TDMs, were identified and provided as inputs to the Technology Development and Flight Experiment Plan.

### 2.2.1 TDM 1 - Resupply of Materials Processing Platform (MPP) Introduction

This mission was rated highest primarily because of a belief that interest in commercial operations in space will accelerate with the reality of a near term Space Station. Discussions with McDonnell Douglas Astronautics Corporation (MDAC) planners associated with experimental Electrophoresis Operations in Space (EOS) activities, revealed plans for a number of orbiting platforms requiring frequent resupply of raw materials. The MDAC schedule would have some of these platforms onorbit requiring servicing prior to the advent of initial Space Station operations, making these missions potentially the highest

priority missions to attempt to capture. There could readily be a customer fully prepared to pay for the servicing economy inherent in this type of servicing mission.

The Resupply of Free Flying Materials Processing Platform (MPP) mission is outlined in Figure 2.2.1-1.

The activities for this mission are summarized in five generic event sequences. First, all mission events required to prepare an OMV and a replacement module transporter (as a "Transfer Stack") for transport to the remote processing platform were outlined. Next, the mated OMV and front end module transport kit was maneuvered away from the Space Station, using inert gas-powered proximity operations, maneuvering motors. This action sequence was followed by the OMV transfer operations needed to rendezvous with the MPP and dock the Transfer Stack (OMV and Module Transporter) with the MPP.

The primary action sequence for TDM1 is the resupply of materials processing modules of the MPP. These will be presented in detailed fashion subsequently; however, the activities surround removal of processed modules from materials processing systems (MPS) or factories, using a teleoperated platform Remote Maneuvering System (RMS). The removal and replacement of raw materials modules in the MPS (Material Processing System) is performed using a MPP mounted RMS. An alternative approach would be to develop a "small front-end" module replacement built for the OMV and to use the kit to perform the module replacement tasks.

The remainder of the mission is essentially a reverse of the previous operations, including return of the Transfer Stack to the Space Station, then demating and reberthing of the Transfer Stack elements. There is, of course, one important additional phase of activities. The OMV is a reusable upper stage and must be refurbished, with all essential actions taken to prepare it for a follow-on mission, prior to reberthing it. The same is true for the module transporter. This sequence of TDM actions is extensive and is outlined in detail, along with TDM 1 derived requirements and precursor technology identified in TDM 1 analyses.

### 2.2.1.1 TDM 1-Functional Flow

For TDM 1, a functional analysis was conducted with two objectives in mind: 1) to derive servicing requirements, and, 2) to describe a representative Space Station that would be used to outline and detail servicing operations/activities. A top level outline of the functional flow, derived requirements, and example Space Station is shown in Figure 2.2.1.1-1.

The servicing requirements/accommodation needs include; an OMV, OMV berthing port(s), operations console(s), refueling depot, SS RMS, a translatable manipulator system, module servicer or transporter, storage for large materials processing modules (current estimates are between 12,000-15,000 pounds), refurbishment equipment for OMV, and system status monitoring equipment and communications equipment.

- PREPARE OMV AND MATERIALS PROCESSING MODULE TRANSPORTER FOR ORBIT TRANSFER.
- DELIVER MODULES TO MPP WITH OMV ORBIT TRANSFER.
- RESUPPLY MPP SYSTEMS (MODULE REPLACEMENT).
- RETURN PROCESSED MODULES TO SPACE STATION.
- REFURBISH REUSABLE OMV.
  - PRE-MISSION TASKS
  - MISSION EVENTS - 3 PHASES
  - POST-MISSION EVENTS

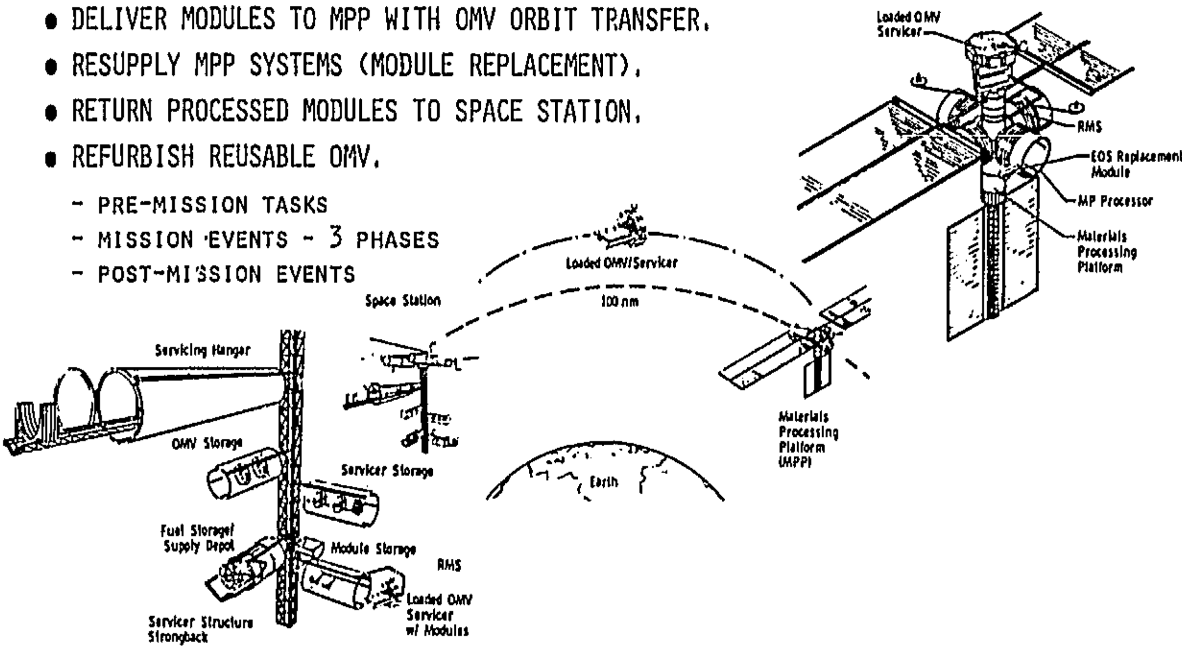



*Figure 2.2.1-1* *TDM 1 - Resupply Free Flying Materials Processing Platform (MPP)*

RESUPPLY MATERIALS PROCESSING PLATFORM (MPP)

DELIVER/STORE OMV FUEL/REFURB EQPT, MPP MODULES AT SPACE STATION → STORE OMV, FUEL FOR TRANSFER TO MPP → MATE OMV AND SERVICER, LOAD MODULES → CONDUCT ORBIT TRANSFER WITH OMV/SERVICER → DOCK OMV/ SERVICER AT MPP → CONDUCT MODULE CHANGEOUT → RETURN PROCESSED MODULES TO SPACE STATION → STORE MODULES, REFURBISH/ BERTH OMV → RETURN PROCESSED MODULES TO EARTH WITH STS

ACCOMMODATION REQUIREMENTS

- OMV, OMV BERTHING/STORAGE, COMMAND/ CONTROL, REFURBISHMENT, REFUELING
- SS RMS, COMMAND CONTROL. ACCESS TO SERVICE FACILITIES
- MODULE SERVICER, BERTHING, STORAGE
- FUEL DEPOT, EARTH STORABLES, PRESSURANTS
- STORAGE, LARGE MODULES, TOOLS, REFURBISHMENT EQUIPMENT
- SYSTEM STATUS MONITORING EQUIPMENT
- COMMUNICATIONS--VOICE, COMMAND/ TELEMETRY VIA TDRSS, GPS

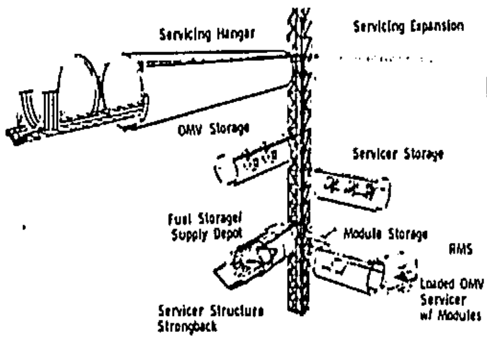



*Figure 2.2.1.1-1 TDM Functional Flow-Servicing Requirements Derivation*

Also shown is the representation Space Station developed to add clarity to a servicing activity description for TDM 1. This hypothetical station included all the servicing elements and support equipment identified in the TDM. Its configuration was based on a favored, at the time, Space Station configuration whose elements were not restricted to one flight plane. The support area is connected to the Space Station by a strongback support element, which was intended to provide "distancing" from the nucleus of the station.

#### 2.2.1.2 Pre-Mission Tasks

The top level activities identified as pre-mission tasks are shown in Table 2.2.1.2-1. Ground-based mission preparations tasks include selection and delivery of the resources required to resupply a free-flying materials processing platform (MPP). These resources include the MPS factory replacement modules, OMV fuels and pressurant gases, and the materials required for OMV refurbishment. In addition, the entire complement of operating procedures required at all operating positions, both on the ground and in space must be generated and tested. Some representative type of procedures are shown on the table.

At the Space Station, these mission resources must be received and properly stored or configured in preparation for startup of the TDM. In addition, mission oriented exercises must be designed and crew exercises conducted.

#### 2.2.1.3 Mission Activity Sequences

The sequence of operations were initially categorized into two distinctive phases: 1) Space Station activities in preparation for orbit transfer; 2) orbit transfer to MPP including rendezvous at MPP, and 3) operations at MPP.

The conceptual Space Station service support area was used to describe the activities in Phase 1 of the TDM. A Space Station Mission Control crewmember operated an RMS console to move the RMS over to the OMV hangar and grapple the OMV. The RMS controller them moved the mated and checked-out OMV to the fuel depot for a remotely conducted refueling. The OMV was attached to the fuel depot and loaded with a mission load of fuel. The OMV was then transported to the servicer hangar, where the OMV and servicer transporter were mated and moved to the module storage facility. The RMS then loaded unprocessed modules into the servicer/processor and the mated OMV/servicer transporter were moved by the RMS to the bottom end of the service strongback for deployment.

The second phase of mission activities included OMV maneuvering away from the Space Station, using inert proximity operations motors, transiting to the MPP, and rendezvous and docking with the Materials Processing Platform.

The OMV will maneuver away from the Space Station at a slow rate to a distance of 2000-3000 feet, to minimize contamination from the plume of the OMV main engines. The OMV operator will complete a transfer maneuver to the MPP, arriving in the vicinity close enough to do a self-contained, GN&C rendezvous using proximity operations engines, to close and enable a Space Station controlled, teleoperated dock at the MPP docking port.

*Table 2.2.1.2-1 Related Pre-Mission Tasks*

GROUND BASED:

- COORDINATE TRANSFER OF MPP RAW MATERIALS MODULE TO SPACE STATION.
- COORDINATE TRANSFER OF OMV FLUIDS/REFURBISHMENT PARTS TO SPACE STATION.
- DEVELOP OPERATIONAL PROCEDURES --
  - OMV PROPELLANT LOADING AT SPACE STATION
  - RMS/OMV MATING, OMV/SERVICER MATING
  - OMV SPACE STATION PROXIMITY OPERATIONS
  - OMV ORBIT TRANSFER OPERATIONS
  - OMV/MPP DOCKING
  - REPLACEMENT MODULE CHANGEOUT
  - OMV REFURBISHMENT OPERATIONS

SPACE STATION:

- RECEIVE/STORE TRANSFER FLUIDS, REPLACEMENT MODULES, OMV REFURBISHMENT PARTS.
- PREPARE EXERCISES, CONDUCT TRAINING FOR TDM.

Phase 3 of this TDM includes all activities while docked at the co-orbiting MPP. Shown in Figure 2.2.1.3-1 is a postulated Space Station co-orbiting Materials Processing Platform with the OMV/Servicer docked. This MPP is considered a viable follow-on Space Station program element, evolving naturally from Space Station Materials Processing Laboratories/Factories and all the precursor development/operations which have transpired. Materials processing systems are expected to grow rapidly, requiring service resources more efficiently provided by a remote co-orbiting platform. The zero-gravity environment, considered requisite to future space-based materials processes, will be enhanced by separation from the random personnel and equipment induced translations of the evolving Space Station. A specifically designed RMS, configured for circular translation around the platform, is seen to be an attractive accommodation need for this element of the Space Station.

A processed module is removed from each MPS and temporarily repositioned on grapple devices on the MPP. A replacement module is removed from the Servicer/Transporter and placed in a Material Processing System (MPS). A finished module is then placed back into the Servicer and latched for transport. When the four modules are transferred and all finished modules are latched in the Servicer/Transporter, the OMV/Servicer is prepared for deployment from MPP and returned to the Space Station.

This TDM was further analyzed to provide a detailed sequence of operations/activities needed to complete the servicing demonstration and validate the capability to perform module replacement operations on free-flyers remotely located from the Space Station. The timelined mission sequence provided in Table 2.2.1.3-1 includes all activities previously discussed in the TDM phases and continues through a description of OMV return to Space Station, refurbishment and reberthing, and preparation for the next mission.

Event sequences are shown with both event and lapsed time. Those activities that are envisioned as being conducted in parallel with others are labeled accordingly. Note on the concluding page of Table 2.2.1.3-1, that OMV refurbishment time is only roughly approximated. The Martin Marietta OMV Phase B contract includes definition of this phase of OMV operations, however, estimates at this time are projections only.

Significantly, this total mission is estimated to require approximately 18 hours, plus OMV refurbishment time to conduct.

The projected implementation of the TDM is 1991-1992. It can be conducted as soon as the requisite precursor activities, described subsequently, are completed. These include installation and validation at Space Station of OMV, fluid depots, and a servicing facility for OMV refurbishment, and support equipment such as Space Station RMS and replacement module transporter.

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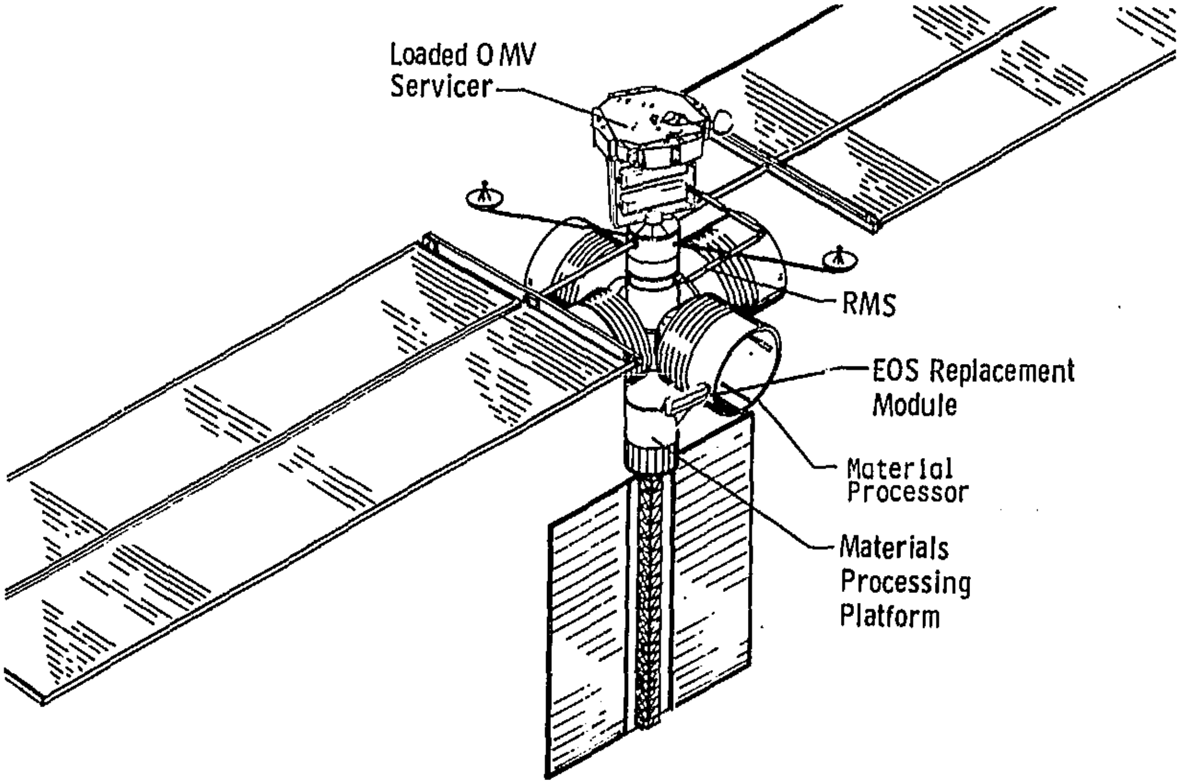


*Figure 2.2.1.3-1 Phase 3 - MPP Operations*

Table 2.2.1.3-1
TDM1 Mission Sequence Event

| Event | Time | Elapsed Time |
|---|---|---|
| Man and activate SSMCC systems and consoles | 15 min | 0 + 15 |
| Checkout OMV ground control system/console | 5 min Parallel | 0 + 15 |
| Checkout OMV SS control system/console | 5 min | 0 + 20 |
| Checkout RMS control system/console | 5 min | 0 + 25 |
| Move RMS to storage facility | 15 min | 0 + 40 |
| RMS latches onto materials processing module transporter. | 5 min | 0 + 45 |
| RMS moves to servicing facility and attaches transporter to servicing facility carousel | 30 min | 1 + 15 |
| RMS moves to OMV berthing port | 15 min | 1 + 30 |
| RMS moves to servicing facility and attaches OMv to transporter. OMV/ transporter hookup now defined as transfer stack | 30 min | 2 + 00 |
| RMS latches onto transfer stack | 5 min | 2 + 05 |
| RMS moves transfer stack to cold gas launch area and berths transfer stack | 30 min | 2 + 35 |
| RMS releases transfer stack and moves clear of launch area | 15 min | 2 + 50 |
| OMV cold gases transfer stack 2000' away from SS | 20 min | 3 + 10 |
| OMV monitors contamination during cold gas transfer | 20 min parallel | 3 + 10 |
| OMV orients towards desired flight track | 1 min | 3 + 11 |
| Switch OMV control to ground control | 1 sec | 3 + 11 |
| OMV transits to desired orbit | 1 hr | 4 + 11 |

Table 2.2.1.3-1 (continued)
TDM1 Mission Sequence Event

| Event | Time | Elapsed Time |
|---|---|---|
| Deactivate SS OMV control stations | 1 min parallel | 4 + 11 |
| Deactivate SS RMS control station | 1 min parallel | 4 + 11 |
| OMV arrives in orbit 2000' ahead of target | N/A | N/A |
| Determine OMV to target range & range rate | 40 sec | 4 + 12 |
| • GPS update of OMV state vector<br>• Calculate relative start vector using on-board calculated target state vector | | |
| Initiate automatic station-keeping with target | 1 sec | 4 + 12 |
| • Continue GPS updates every 6 seconds<br>• Execute required RCS correction burns | | |
| Initiate LVLH hold mode: Acquire horizon sensor readings | 30 sec | 4 + 13 |
| • Update OMV attitude reference | | |
| Establish video data link: | 10 sec | 4 + 13 |
| • Establish TRDS link<br>• Camera 1 on<br>• Video processor on<br>• Select video search frame rate (5 frame/sec | | |
| Verify OMV subsystem performance: | 10 sec | 4 + 13 |
| • Video Comm, command link<br>• RCS propulsion<br>• Extend end effector<br>• Safe OMV man engines<br>• Verify eng. data in limits | | |
| Search for and acquire target: | 4 min | 4 + 17 |
| • Visual examination of video screen until target detected | | |

Table 2.2.1.3-1 (continued)
TDM1 Mission Sequence Event

| Event | Time | Elapsed Time |
|---|---|---|
| Prepare to close | 40 sec | 4 + 17 |
| • Center target in screen<br>• Select motion detection frame rate (1 frame/sec)<br>• Determine R and $\dot{R}$<br>• Apply + X$\Delta$V to close | | |
| Video close from 2000' $\overline{V}$: | 13 min | 4 + 30 |
| • Apply Y and Z thrust to maintain target centered<br>• Brake as closing velocity is sensed<br>• Brake to stop at -200' $\overline{V}$<br>• Turn on camera 2 | | |
| Perform transition maneuver to move around radius vector at a 200' standoff to docking probe axis | 5 min | 4 + 35 |
| • Apply initial translation thrust<br>• Maintain target distance with +X thrust<br>• Visually inspect target, verify cooperative conditions<br>• Apply braking thrust to align on docking probe axis<br>• Select Prox Ops frame rate (5 frames/sec) | | |
| Close 40' standoff point: | | |
| • Activate cold gas RCS<br>• Apply +X thrust<br>• brake as closing velocity is sensed<br>• Turn on OMV docking light at 100'<br>• Brake to standoff at 40' | 6 min | 4 + 41 |
| Inspect and configure target | 1 min | 4 + 42 |
| • Operate pan tilt search w/camera 2<br>• Verify docking probe system and approach path<br>• Configure target for docking<br>• Roll to target alignment<br>• Verify proper docking orientation<br>• Turn on power to docking mechanism<br>• Flight director approves go for dock (lighting, TDRSS coverage adequate) | | |

Table 2.2.1.3-1 (continued)
TDM1 Mission Sequence Event

| Event | Time | Elapsed Time |
|---|---|---|
| Close from 40' to docking envelope | 6 min | 4 + 48 |
| • Apply +X thrust to close<br>• Apply thrust as necessary to align target in video screen reticles<br>• Hold position for 15 sec. once target ready for capture | | |
| Target capture and hard dock or grapple | 2 min | 4 + 50 |
| • Close end effector snares<br>• Retract snares for rigid dock<br>Retract end effector<br>• Engage hard dock latches<br>• Turn off power to docking mechanism | | |
| MMP RMS grapples expended materials processing module/berths expended module on temporary holding station at MMP | 30 min | 5 + 20 |
| MMP RMS moves to transfer stack/grapples replacement materials processing module/ connects replacement module inside MMP factory | 30 min | 5 + 50 |
| MMP RMS grapples expended module on holding station and berths it to materials processing module transporter | 30 min | 6 + 20 |
| Repeat above 3 sequences 3 more times until all expended modules are replaced | 4 + 30 | 10 + 50 |
| Configure OMV for orbit adjust maneuver | 5 min | 10 + 55 |
| Orient for Orbit adjust burn | 5 min | 11 + 05 |
| Transit to Space Station: Take station 2000' away from SS | 60 min | 12 + 05 |
| Check out RMS control system/console | 5 min parallel | 12 + 05 |
| Checkout fueling depot control system/ console | 15 min parallel | 12 + 05 |
| Switch control of OMV from ground control to SS | 1 sec parallel | 12 + 05 |
| Move RMS to OMV berthing port | 14 min parallel | 12 + 05 |

Table 2.2.1.3-1 (concluded)
TDM1 Mission Sequence Event

| Event | Time | Elapsed Time |
|---|---|---|
| Deactivates OMV main engines | 1 sec | 12 ÷ 05 |
| Cold gas thrust OMV to berthing port | 20 min | 12 + 25 |
| OMV monitors contamination surrounding SS | 20 min parallel | 12 + 25 |
| RMS latches onto transporter/transporter released from OMV | 5 min | 12 + 45 |
| RMS moves transporter to storage hanger/berths transporter | 30 min | 13 + 15 |
| RMS moves to OMV berthing port/latches onto OMV | 15 min | 13 + 30 |
| RMS moves/berths OMV to fuel depot | 30 min | 14 + 00 |
| RMS connects defueling lines to OMV | 30 min | 14 + 00 |
| Defuel OMV | 60 min | 15 + 30 |
| RMS disconnects defueling lines/stow lines moves/berths OMV to servicing facility carousel for refurbishment | 5 min | 15 + 35 |
| Refurbish OMV (routine-extended) | 3-12 hrs | N/A |
| • Connect test equipment umbilicals to OMV test ports using servicing facility RMS<br>• Visually inspect OMV outer structure using TV camera<br>• Replace OMV modules failing test and modules scheduled for replacement (EVA required) | | |
| RMS moves OMV to fueling depot | 30 min | 16 + 05 (+ refurbishment) |
| RMS connect required umbilicals to OMV/OMV fueled | 90 min<br><br>ment) | 17 + 35 (+ refurbish- |
| RMS disconnects umbilicals and moves/berths OMV to OMV berthing port | 30 min | 18 + 05 (+ refurbishment) |

### 2.2.1.4 Post-Mission Activities

The TDM mission boundary has been defined in the previous paragraph. Within the framework of that definition, are several "post-mission" activities.

At the Space Station, OMV fuels and pressurants must be replaced, contamination residue must be cleaned/removed, and processed materials modules must be temporarily stored at Space Station and scheduled for return to earth in STS return flights.

On the ground, the processed modules must be returned to users, and new modules scheduled for delivery to Space Station. Most importantly, all procedures used in the TDM must be reviewed, "lessons learned" applied and new procedures developed for follow-on user operations.

### 2.2.1.5 Precursor Activates

Precursor activities are those: 1) servicing technology developments, new starts, program accelerations; 2) STS flight experiments required to provide zero-gravity validation of concepts; and 3) Space Station validation tests that must be accomplished prior to the conduct of a servicing TDM. A summary of these precursors are shown in Table 2.2.1.5-1.

The first category includes development and validation of Space Station service support elements and equipment including the SS RMS, servicing hanger, fuel storage and resupply depot, and a broad range of berthing and storage facilities. Precursors include the basic technology development required to enable use of these servicing elements. These include fluid transfer management, teleoperated docking, and developments for OMV autonomous rendezvous operations.

Materials processing precursor activities include development of the ground process and equipment, STS process verification in zero-gravity, middeck experiments, cargo bay production facility verification, and free-flyer development and test activities. For resupply at remote platforms, an OMV intelligent servicer front end may be selected; require development, STS/OMV validation tests, and operations validation at the Space Station, prior to conduct of the TDM at a remote free flyer.

A reusable Space Station based OMV will also require a lengthy series of operations validation tests, as shown.

### 2.2.1.6 TDM Issues/Trades

During the detailed definition of the MPP resupply mission, a variety of alternative approach issues were raised. These issues suggest the need for trade studies that were considered outside the scope of the contract. It is useful, however, to present them now for the consideration of servicing planners and other study servicers.

*Table 2.2.1.5-1 Precursor Activities*

- SPACE STATION SERVICE SUPPORT AREA/EQUIPMENT VALIDATION --
  - SPACE STATION RMS, MAINTENANCE FACILITY, FUEL STORAGE/RESUPPLY DEPOT, TRANSFER VEHICLE/SERVICER/MODULE BERTHING/STORAGE FACILITIES.
- MATERIALS PROCESSING MODULE REPLACEMENT VALIDATION --
  - MODULE DEVELOPMENT, GROUND PRODUCTION, SIMULATED ZERO-G TESTS;
  - MID-DECK, CARGO BAY PRODUCTION VERIFICATION, FREE-FLYER PRODUCTION;
  - SPACE STATION MATERIALS PROCESSING LABORATORIES/FACTORIES, MODULE REPLACEMENT WITH RMS;
  - REMOTE SERVICER DEVELOPMENT, OMV/SERVICER MATING, OPERATIONS AT SPACE STATION.
- REUSABLE OMV OPERATIONS VALIDATION --
  - SPACE STATION BERTHING, PROXIMITY OPERATIONS AROUND SPACE STATION;
  - INTERFACES WITH RMS, SERVICER;
  - REMOTE OPERATIONS USING TELEPRESENCE (RENDEZVOUS, DOCKING);
  - ORBIT TRANSFER OPERATIONS;
  - VEHICLE REFURBISHMENT OPERATIONS.

The first issue requiring trade consideration relates to the means for providing module changeout at the remote platform. One approach is to use that suggested in the TDM definition, the option of building-in a translatable manipulator at the platform to enable automated, remote controlled module changeout. However, it is the study team's conviction that EOS platforms will be flying prior to Space Station, and will be configured for STS RMS changeout or changeout using EVA procedures. If this assertion proves to be correct, an alternative is to seek a higher priority on technology related to remote-teleoperated module changeout using an OMV front end kit. STS experiments are in planning for both robotic fluid transfer and robotic module changeout, with programs out of MSFC.

Remote module changeout for customers, such as EOS, are likely to increase in scope and magnitude, and are logical candidates for early Space Station mission capture.

Another issue regards whether mission control of remote changeout operations should reside at Space Station, onorbit mission control, or be controlled from Space Station ground control. The issue suggests trades in control mode time delays and those impacts on operations, and on the impact on Space Station operations, of controlling the missions from the manned station.

Several issues pertaining to OMV operations at the Space Station were raised during detailed definitions. The question of whether OMV, assuming it uses storable fluids, should be loaded totally for each mission or whether only a mission load plus reasonable margins, should be provided. Another OMV concern surrounded the questions of safety, whether the operations could be conducted by EVA astronauts with adequate safety provisions. Appropriate trades are recommended for resolution of these issues.

Space Station remotely operated equipment, such as the SS RMS, OMV, OTV, fuel depot, front end servicers, etc., will require control consoles within SSMC (mission control). There are questions relating to whether the control consoles should be single or multiple purpose. This decision has significant impacts, perhaps on manning, and certainly on the manner in which servicing operations will be conducted.

A final issue addresses the question of how much, if any, shielding is needed for OMV storage, for servicer and replacement module storage, etc. Many Space Station elements will require shielding from specific space environment threats; i.e., micrometeoroid bombardment, thermal effects, and various radiation effects.

Trades to ascertain specific requirements will be needed to deal with these issues.

### 2.2.2 TDM 2 - Retrieve/Repair AXAF at Space Station

This TDM was rated high initially because of the multiple servicing tasks demonstrated by it. These include: satellite retrieval from orbit and return (delivery) to operational orbit; resupply operations at Space Station including module replacement, and instrument bottle/tank replacement (or fluid transfer); maintenance activities including preventive maintenance in battery replacements and replacement of other equipment expendables; repair of a variety of potential failures including possible refurbishment of antennas and solar arrays (given technology advancements) and finally; potential retrofit of new instrument or spacecraft systems. A number of candidates were considered for this mission and the Advanced X-ray Astrophysics Facility (AXAF) was selected because of the extensive level of onorbit servicing already included in the planning for the mission.

The outline of TDM 2, AXAF retrieval and repair at Space Station, is illustrated in Figure 2.2.2-1.

AXAF will be deployed initially to 320 nautical miles (nm) in a 28.5 degree inclination orbit. The current planned mission life for AXAF is fifteen years, and repair/resupply missions are being scheduled to be completed every three years, using the STS primarily. During each three year period, AXAF's orbit will decrease to 205 nm, and at the time, it is recommended that a Space Station OMV be dispatched to the AXAF depleted orbit to retrieve it. The OMV will rendezvous with AXAF, which has been prepared for pickup by its Payload Operations Control Center (POCC). AXAF antennas will be stowed, contamination ports closed and the spacecraft inerted for safe mutual OMV/AXAF mating and transport to the Space Station.

The major activity sequences as shown are: 1) the retrieval of AXAF from a degraded low earth orbit with OMV; 2) the completion of a large number of potential resupply and maintenance activities conducted on the AXAF while berthed in the Space Station servicing hangar; 3) the return of AXAF to its correct operational orbit; and 4) the return of OMV to Space Station and refurbishment prior to reberthing.

A representative Space Station satellite servicing support area was developed to facilitate description of the servicing activities. This configuration, shown in Figure 2.2.2-2, is different from the configuration shown for TDM 1, primarily because it is a planar configuration with all servicing components situated in one plane in the direction of forward motion of the Space Station. This configuration had gained in popularity in the evolving Space Station configuration studies.

- RETRIEVE ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF) FROM LOW EARTH ORBIT. FERRY TO SPACE STATION.
- CONDUCT SERVICING OPERATIONS AT SPACE STATION MAINTENANCE FACILITY --
  - REPLACE SCIENCE INSTRUMENT ORUs (9 MAXIMUM)
  - REPLACE DEPLETED INSTRUMENT GAS BOTTLES WITH CHARGED BOTTLES (5 BOTTLES)
  - REPLACE SPACECRAFT SUBSYSTEM ORUs (16 MAXIMUM)
- RETURN AXAF TO OPERATIONAL ORBIT WITH OMV.
- RETURN OMV TO SPACE STATION AND REFURBISH.

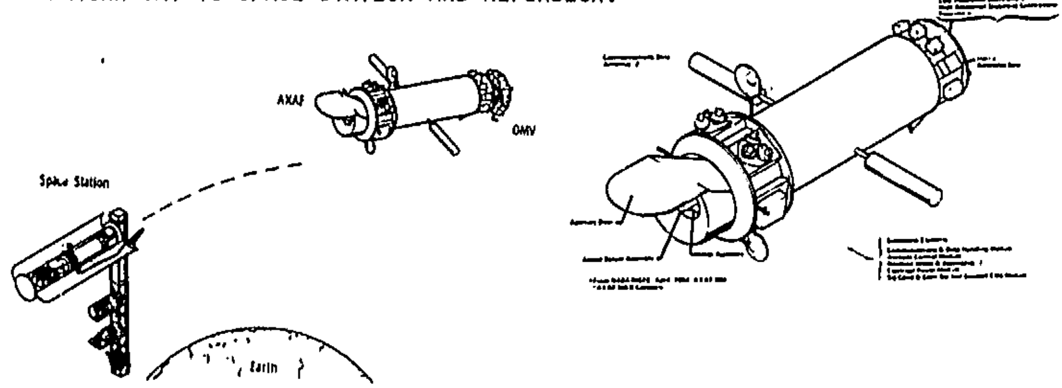


*Figure 2.2.2-1 TDM 2 - Retrieve/Repair AXAF at Space Station*

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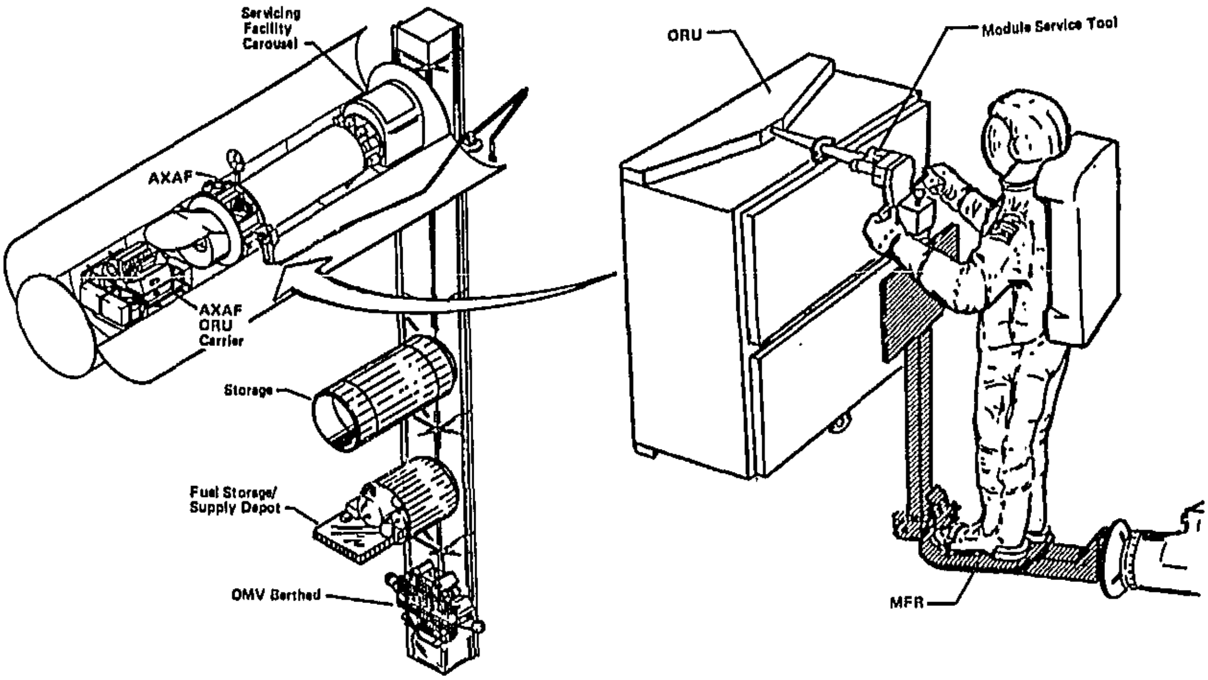



*Figure 2.2.2-2 AXAF Repair/Resupply*

### 2.2.2.1 TDM 2 - AXAF Pre-Mission Tasks

As in TDM 1, the detailed definition of TDM 2 revealed a number of activities considered related to conduct of the mission. Ground based pre-mission tasks include the delivery to Space Station of an AXAF Orbital Replacement Unit (ORU) module carrier, a rotating carousel mechanism designed to hold a large contingent of AXAF modules and provide convenient presentation to astronauts in EVA. In addition, special AXAF tools must be delivered to the Space Station prior to TDM initiation. All of the replacement modules, to be shown later, including spacecraft/scientific instrument modules, gas bottles, batteries, antennas, and solar panels must be delivered to the Space Station. The operation procedures and training programs must be developed and validated on the ground, in a manner similar to the process used to prepare for the Solar Maximum Repair Mission (SMRM).

At the Space Station, the first pre-mission tasks include receipt and storage of all equipments and repair/resupply materials. The previously verified test procedures will be exercised again, and crew training conducted, along with realistic simulation activities.

### 2.2.2.2 TDM 2 - Mission Event Sequence

An overview of the projected AXAF retrieval/repair mission is provided in Table 2.2.2.2-1. These activities include several activity sequences already described in TDM 1 and other sequences that are common to one or more of the remaining sequences. To avoid repetition throughout the lengthy TDM mission sequence descriptions, Appendix A, Common Activity Sequences was developed. Throughout this and subsequent TDM descriptions, the reader will be directed to the appropriate Table in Appendix A for expanded definitions of common TDM activity sequences.

Thus, the Mission Event Sequence description for TDM 2 outlines the totality of events initiated by preparation of OMV for its flight to retrieve AXAF (Table A), rendezvous, grapple and return to Space Station of AXAF, (including Tables B and C), repair and resupply activities in the service hangar/facility (including tables E, F, G and H), return of AXAF to an upgraded operational orbit, and completed with return of OMV to Space Station for refurbishment and reberthing.

As will be described subsequently, there are a substantial number of repair and resupply tasks that could be performed on AXAF, as required, for each mission. The estimates range from as few as 1 to 2 days up to 8 to 10 days.

Table 2.2.2.2-1 TDM 2 Mission Event Sequence

| Event | Time | Elapsed Time |
|---|---|---|
| Prepare OMV for flight (Table A) | 2 + 48 | 2 + 48 |
| OMV transits to orbit/rendezvous/docks with AXAF (Table B) | 1 + 42 | 4 + 30 |
| OMV returns to SS with AXAF (Table C) | 2 + 20 | 6 + 50 |
| RMS grapples OMV/AXAF | 5 min | 6 + 55 |
| RMS berths OMV/AXAF to OMV berthing port | 15 min | 7 + 10 |
| RMS grapples AXAF/AXAF released from OMV/AXAF moved to temporarily berthing port/berthed | 15 min | 7 + 25 |
| OMV refurbished (Table D) | 5 hr (+ refurbishment) | 12 + 25 (+ refurbishment) |
| RMS grapples AXAF/moves AXAF to servicing facility/berths AXAF to servicing facility carousel | | |
| Refurbish AXAF | 8 days | 12 + 25 (+ AXAF refurbishment + OMV refurbishment) |

- Astronauts prepare for EVA (Table E)
- Astronauts transferred to servicing facility (Table F)
- Astronauts perform refurbishment tasks (Table G)
- Astronauts return to airlock (Table F)
- Post EVA activity (Table H)
- Repeat above tasks for each EVA day
- Typical EVA day follows: 6 EVA hrs/man

Disconnect/remove/replace science instrument modules failing component test and those scheduled for replacement

EVA #1 open aft end hinged door exposing science instrument modules

- Disconnect 1st faulty instrument module

Table 2.2.2.2-1 TDM 2 Mission Event Sequence (Concluded)

| Event | Time | Elapsed Time |
|---|---|---|
| • EVA #1 tells EVA #2 which module is being removed | | |
| • EVA #2 removes replacement module from resupply carousel | | |
| • Remove 1st faulty instrument module | | |
| • Move 1st faulty instrument module with EVA #1 and servicing facility RMS (SFRMS) to EVA #2 | | |
| • Give 1st faulty instrument module to EVA #2 | | |
| • EVA #2 receives 1st faulty instrument module | | |
| • EVA #2 places faulty instrument in AXAF ORU resupply carousel | | |
| • EVA #2 gives EVA #1 replacement module | | |
| • EVA #1 returns to aft end of AXAF | | |
| • EVA #1 replaces and connects | | |
| Repeat for each faulty/scheduled replacement instrument | | |
| Form transfer stack with OMV and AXAF (Table I) | 3 + 11 | 15 + 36 (+ AXAF refurbishment + OMV refurbishment) |
| OMV transits to desired orbits/releases AXAF | 1 + 30 | 16 + 06 (+ AXAF refurbishment + OMV refurbishment) |
| OMV returns to SS (Table C) | 2 + 20 | 18 + 26 (+ AXAF refurbishment + OMV refurbishment) |
| OMV refurbished (Table D) | 5 hr + refurbishment | 23 + 26 (+ AXAF refurbishment + 2 OMV refurbishment) |

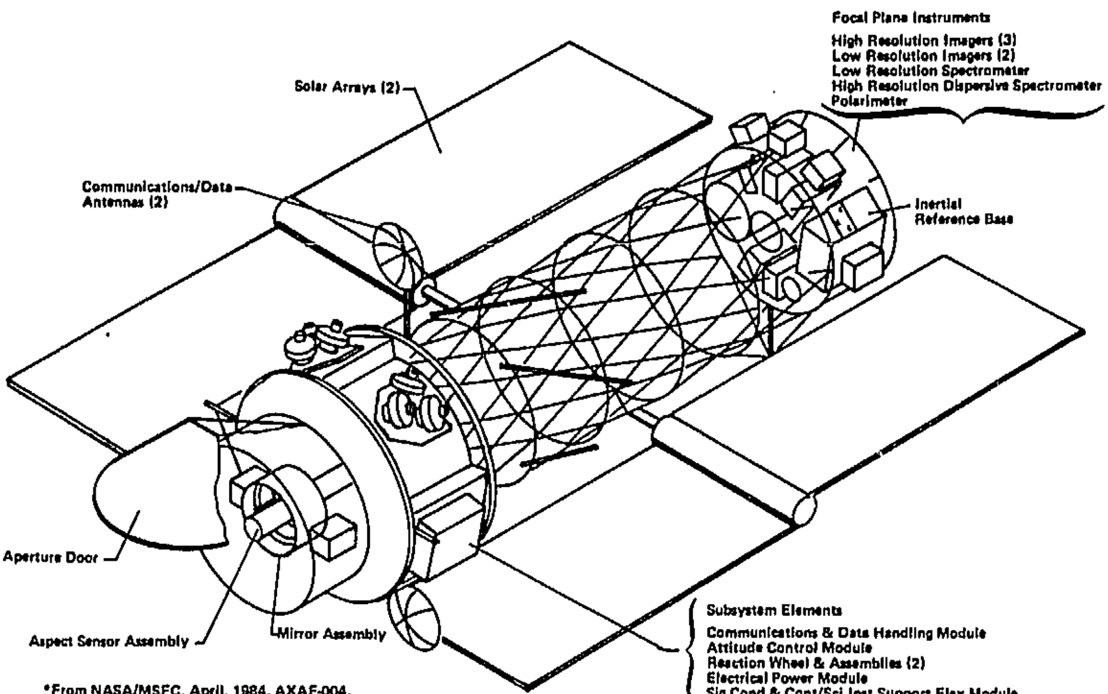
### 2.2.2.3 AXAF Configuration for Servicing

Throughout the 18 month period of performance of this study contract, Martin Marietta communicated frequently with the AXAF program office, particularly with a group associated with servicing plans for AXAF. An AXAF servicing document entitled, "AXAF Maintenance and Repair Concepts", NASA/MSFC, AXAF-004, April, 1984, provided excellent support to the TDM 2 definition task. As shown in Figure 2.2.2.3-1, the AXAF satellite, including spacecraft/scientific instrument elements, is configured extensively for servicing. AXAF planners are currently considering five servicing missions over a 15 year period of operations, including final retrieval and return to earth. The spacecraft and scientific systems have been designed with accessibility to essentially every system component. Table 2.2.2.3-1 highlights the level of servicing activities being considered by AXAF planners. Spacecraft subsystems to be configured for onorbit replacement total 18 in number, including systems such as the solar arrays and the aspect sensor assembly. Replacement of the aspect sensor assembly will be a challenging servicing task, principally because of sensor handling activities and the necessity for stringent contamination control during operations. In addition, servicing planners have considered 23 science instrument subsystems for onorbit replacement, and are considering development of orbital replacement units (ORUs) for each of these.

AXAF planners are also considering a pallet-based "ORU Carrier", that would carry an entire complement of replacement articles, ORUs, gas bottles, batteries, etc. on a rotating carousel structure. The ORU carrier is shown in Figure 2.2.2.3-2. The structure supports four multi-mission modular spacecraft (MMS) modules. Additional small modules would be carried in spaces not occupied by instruments, since it is not anticipated that a full load of instruments would be taken up for any of the repair missions. The carousel allows convenient "parts presentation" and each ORU has a payload fitting for attachment to the manipulator foot restraint (MFR) payload interface mechanism.

AXAF is making maximum application of standardized interfaces, tools, and procedures from prior spacecraft which were designed for onorbit repair capability. This technology, rooted largely in the MMS, has been flight-proven by the Solar Max Mission and has been used in the design of Solar Max, Landsat, Space Telescope, GRO, and UARS. This heritage has been fully applied to AXAF Space Station Maintenance and Repair (M&R) planning and experience from these programs will continue to influence AXAF and its Space Station M&R missions. The AXAF onorbit repair technology base is illustrated in Figure 2.2.2.3-3.

An estimation of specific AXAF servicing time for the first AXAF mission is premature at this time. However, a series of eight EVA activity days were detailed to investigate the operational aspects of this servicing demonstration mission and to refine estimates of Space Station requirements and accommodations. An example of this analysis is shown in Table 2.2.2.3-2. This is the second planned EVA day, and this day is dedicated to removal of faulty scientific instrument ORUs. Recall that AXAF is configured for replacement of 23 of these subsystem elements. The operational timeline includes EVA preparation, transit to the service hangar and ORU replacement time. Estimates were based on experience gained on Solar Maximum ORU replacement.




*From NASA/MSFC, April, 1984, AXAF-004, "AXAF M&R Concepts."

*Figure 2.2.2.3-1 Current AXAF ORU Baseline*

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*Table 2.2.2.3-1 AXAF ORU Equipment Complement*

| SCIENCE INSTRUMENTS | ORU'S | ELECTRONIC MODULES | GAS SUPPLY ORU'S |
|---|---|---|---|
| MRI- MODERATE RESOLUTION IMAGER | 2 | 2 | 2 |
| HRDS- HIGH RESOLUTION DISPERSIVE SPECTROMETER | 1 | 1 | 2 |
| MRS- MODERATE RESOLUTION SPECTROMETER | 1 | 1 | - |
| FPP- FOCAL PLANE POLARIMETER | 1 | 1 | 1 |
| HRI- HIGH RESOLUTION IMAGER | 3 | 3 | - |
| MPC- MONITOR PROPORTIONAL COUNTER | 1 | 1 | - |
| TOTAL | 9 | 9 | 5 |

| SPACECRAFT SUBSYSTEMS | ORU'S |
|---|---|
| SCCU/SISE- SIGNAL CONDITIONING AND CONTROL UNIT/ SCIENCE INSTRUMENT SUPPORT ELECTRONICS | 1 |
| ACS- ATTITUDE CONTROL SYSTEM | 1 |
| C&DH- COMMUNICATIONS AND DATA HANDLING | 1 |
| EPS- ELECTRICAL POWER SYSTEM | 1 |
| REACTION WHEEL | 2 |
| INERTIAL REFERENCE BASE | 1 |
| SOLAR ARRAYS | 2 |
| MAGNETIC TORQUER | 6 |
| ASPECT SENSOR | 1 |
| ANTENNAS | 2 |
| TOTAL | 18 |

*TOTAL NUMBER OF REPLACEABLE MODULES: 41*

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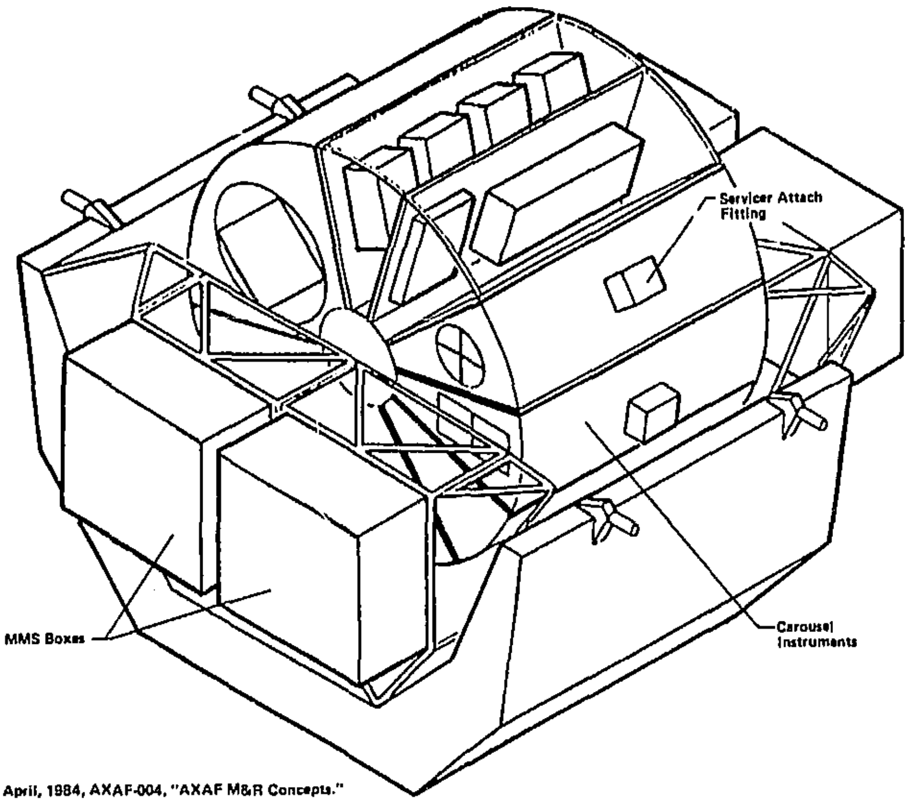


*From NASA/MSFC, April, 1984, AXAF-004, "AXAF M&R Concepts."

*Figure 2.2.2.3-2 AXAF ORU Carrier*

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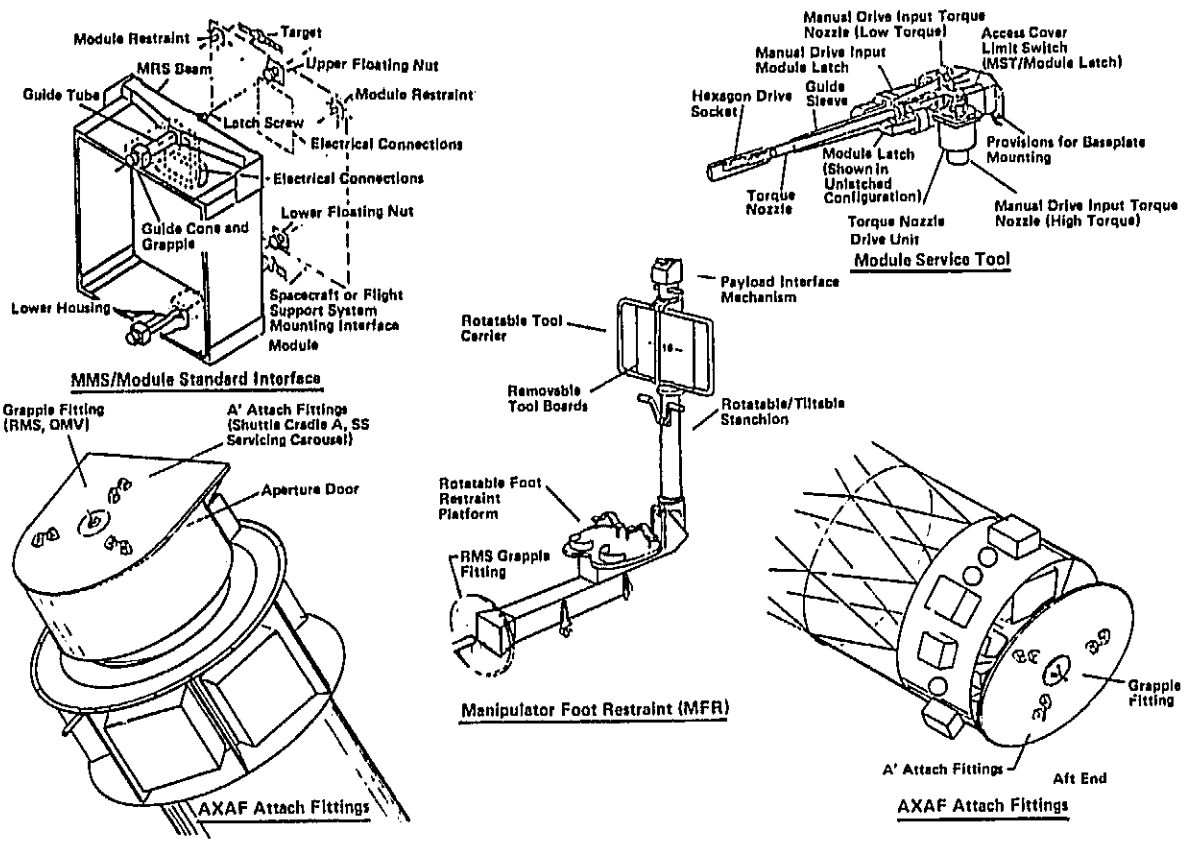


*Figure 2.2.2.3-3   AXAF Heritage - On-orbit Repair Technology*

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Table 2.2.2.3-2 AXAF Module Replacement Operational Timeline

| EVENT | CREW | CONTROL MAN | CONTROL AUTO | EVENT TIME | ELAPSED TIME | SUPPORT EQUIPMENT |
|---|---|---|---|---|---|---|
| MOVE 2 EVA ASTRONAUTS FROM AIRLOCK TO SERVICING FACILITY | 2 EVA, 1 IVA | 100 | | 35 MIN | 0+35 | SS RMS CONTROL/ SS RMS |
| PREPARE TO SERVICE AXAF | | | | | | |
| • GET PROPER TOOLS | | 100 | | 10 MIN | 0+35 | |
| • MOUNT MFR TO SERVICING FACILITY RMS | | 100 | | 10 MIN | 0+35 | SERVICING RMS |
| • EVA #1 MOUNTS MFR AND MOVES TO SCIENCE INSTRUMENT HOUSING ON AXAF | 2 EVA, 1 IVA | 100 | | 10 MIN | 0+45 | SERVICING RMS |
| SERVICE SCIENCE INSTRUMENTS | | | | | | |
| • OPEN AFT HINGED DOOR OF AXAF | 2 EVA, 1 IVA | 100 | | 15 MIN | 1+00 | SERVICING RMS MODULE SERVICE TOOL |
| • DISCONNECT HRS MODULE | 1 EVA, 1 IVA | 100 | | 15 MIN | 1+15 | SERVICING RMS MODULE SERVICE TOOL |
| • EVA #2 REMOVES REPLACEMENT HRS MODULE FROM RESUPPLY CAROUSEL | 1 EVA | 100 | | 10 MIN | 1+15 | |
| • EVA #1 REMOVES EXPENDED HRS MODULE FROM AXAF | 2 EVA, 1 IVA | 100 | | 5 MIN | 1+20 | SERVICING RMS MODULE SERVICE TOOL |
| • MOVE EXPENDED HRS TO RESUPPLY CAROUSEL | 2 EVA, 1 IVA | 100 | | 10 MIN | 1+30 | SERVICING RMS |
| • EVA #2 PLACES EXPENDED HRS MODULE IN RESUPPLY CAROUSEL | 1 EVA, 1 IVA | 100 | | 10 MIN | 1+40 | MODULE RESUPPLY CAROUSEL |
| • EVA #1 RETURNS TO AFT END OF AXAF WITH REPLACEMENT HRS MODULE | 1 EVA | 100 | | 10 MIN | 1+40 | SERVICING RMS |
| • EVA #1 REPLACES AND CONNECTS REPLACEMENT HRS MODULE IN AXAF | 2 EVA, 1 IVA | 100 | | 20 MIN | 2+00 | SERVICING RMS MODULE SERVICE TOOL |
| • EVA #1 DISCONNECTS HRDS MODULE | 1 EVA, 1 IVA | 100 | | 15 MIN | 2+15 | SERVICING RMS MODULE SERVICE TOOL |
| • EVA #2 ROTATES RESUPPLY CAROUSEL | 1 EVA | 100 | | 5 MIN | 2+15 | MODULE RESUPPLY CAROUSEL |
| • EVA #2 REMOVES REPLACEMENT HRDS MODULE FROM RESUPPLY CAROUSEL | 1 EVA | 100 | | 10 MIN | 2+15 | MODULE RESUPPLY CAROUSEL |
| • EVA #1 REMOVES EXPENDED HRDS MODULE FROM AXAF | 2 EVA, 1 IVA | 100 | | 5 MIN | 2+20 | SERVICING RMS MODULE SERVICE TOOL |
| • MOVE EXPENDED HRDS TO RESUPPLY CAROUSEL | 2 EVA, 1 IVA | 100 | | 10 MIN | 2+30 | SERVICING RMS MODULE SERVICE TOOL |
| • EVA #2 PLACES EXPENDED HRDS MODULE IN RESUPPLY CAROUSEL | 1 EVA, 1 IVA | 100 | | 10 MIN | 2+40 | MODULE RESUPPLY CAROUSEL |
| • EVA #1 RETURNS TO AFT END OF AXAF WITH REPLACEMENT HRDS MODULE | 1 EVA | 100 | | 10 MIN | 2+40 | SERVICING RMS |
| • EVA #1 REPLACES AND CONNECTS REPLACEMENT HRDS MODULE IN AXAF | 2 EVA, 1 IVA | 100 | | 20 MIN | 3+00 | SERVICING RMS MODULE SERVICE TOOL |
| • REPEAT FOR EACH FAULTY/ SCHEDULED REPLACEMENT INSTRUMENT | 2 EVA, 1 IVA | 100 | | AS RQD | AS RQD | |
| RETURN 2 EVA ASTRONAUTS TO AIRLOCK | 2 EVA, 1 IVA | 100 | | 35 MIN | 6+00 | SS RMS CONTROL, SS RMS |

Upon completion of AXAF servicing, return to orbit, and return of OMV to Space Station for refurbishment and reberthing, the actual TDM activity is complete.

### 2.2.2.4 AXAF Post Mission Activities

AXAF post-mission tasks are limited in scope. The mission specific equipment including the AXAF ORU carrier, a rotating carousel containing all AXAF ORUs situated temporarily in the service facility for convenient presentation of ORUs to the astronauts (Figure 2.2.2.3-1), must be returned to earth to avoid unnecessary accumulation at Space Station. Also, OMV fuels and pressurant levels must be retained at proper levels, so these may require replenishment. Finally, this mission is a multi-service oriented mission, with a large number of "lessons learned" anticipated. The equipment and operations used in the mission will be thoroughly reviewed to refine related follow-on missions.

### 2.2.2.5 TDM 2 Precursor Activities

During detailed definition of TDM 2, a number of "precursor" activities were identified. Precursor activities are defined as those technology development and requisite onorbit technology verification enterprises that must be undertaken or completed to enable conduct of the TDM. For the AXAF retrieval/repair mission, those precursor activities are shown in Table 2.2.2.5-1. A space-based reusable OMV must be developed, tested repeatedly in various STS flight experiments, and validated for operations at Space Station, utilizing the accommodations provided at Space Station to support OMV operations. OMV onorbit operations are dependent on resolution of fluid transfer management issues, including onorbit fluid transfer, mass gauging, leak proof quick disconnects, and onorbit storage of both storable and cryogenics.

Another precursor technology activity that must be initiated on ground, and then space validated is the design and development of the Space Station service support area. Though perhaps an obvious precursor activity, it is included to ensure full precursor description.

For AXAF, the design and development of the ORU carrier must be completed to enable conduct of this TDM. Every effort should be made to ensure use of standard tools being developed for similar missions, such as for Space Telescope on the STS.

STS Flight Experiments are a second category of TDM precursor activities. Those new technology starts requiring onorbit validation, such as fluid transfer, can be accommodated efficiently by STS flight experiments. Demonstrations of onorbit refueling of OMV will be performed using the STS. Demonstrations of fuel transfer from Space Station fuel storage depots are logical STS flight experiment candidates. Docking and berthing of OMV, mating of OMV and free-flying satellites, and OMV/Space Station proximity operations are additional flight experiment initiatives.

*Table 2.2.2.5-1 Precursor Activities*

- OMV VALIDATION -- SAME AS MPP TDM.
- SPACE STATION SUPPORT AREA VALIDATION -- SAME AS MPP TDM.
- SERVICE FACILITY VALIDATION --
  - DESIGN, DEVELOP, GROUND TEST FACILITY;
  - DELIVER, CONSTRUCT, TEST AT SPACE STATION;
  - DESIGN, DEVELOP, GROUND TEST GENERAL PURPOSE ROBOTIC SERVICER (PAYLOAD CRADLE/CARRIAGE, CAROUSEL MECHANISM);
  - DELIVER, TEST SERVICER/AXAF SPECIFIC TOOLS IN STS/AT SPACE STATION.
- AXAF REPAIR ACTIVITY VALIDATION --
  - DESIGN, GROUND TEST AXAF ACCESS PANELS/MODULES/TANKS AND TANK/MODULE REPLACEMENT PROCEDURES;
  - CONDUCT APPROPRIATE STS FLIGHT EXPERIMENT TESTS;
  - DELIVER AND TEST MODULES, CONDUCT TANK/MODULE EXCHANGE TRAINING.
  - MODIFY A SPAS-TYPE PALLET TO CREATE AN AXAF TEST VEHICLE INCLUDING HIGH FIDELITY AXAF/OMV AND AXAF/SERVICER FACILITY INTERFACES. INCLUDE REPRESENTATIVE HIGH FIDELITY ORUs WITH INTERFACES TO AXAF ORU CARRIER, AXAF, AND MFR.
  - PERFORM STS FLIGHT EXPERIMENTS AND SPACE STATION TESTS, TRAINING, AND DEVELOP PROCEDURES USING AXAF TEST VEHICLE, AXAF ORU CARRIER, OMV, SERVICER FACILITY, STANDARD AND AXAF-SPECIFIC TOOLS, MOBILE RMS, AND MFR.

Space Station validation of satellite servicing support elements and equipment will also be required prior to initiation of the AXAF resupply/ repair TDM. The servicing support equipment; i.e., service hangar, OMV berth, storage hangars/facilities and fluid depots must be installed and appropriately tested/exercised. Special AXAF support equipment must be delivered to Space Station and verified using exercise scenarios.

A final phase of precursor activities at Space Station is a recommended simulation of the actual AXAF repair mission. Solar maximum repair mission "lessons learned", suggests the modification of a SPAS-type pallet to create a high-fidelity mockup of AXAF. This mockup would require AXAF/OMV, AXAF service hangar and AXAF/ORU interfaces to enable Space Station proximity operations testing. OMV would deploy to retrieve the mockup and return it to the service facility. Servicing simulation activities, including ORU replacement and antenna or solar array replacement/refurbishment, would then be conducted on the AXAF mockup in the service hangar.

These precursor activities represent a top level evaluation of the types of technology development and flight experiments required to prepare for the AXAF servicing demonstration mission, and this data served as an input to the Technology Development and Flight Experiment Plan.

A final step in the definition of TDM 2 was the development of a Technology/TDM Implementation Plan for the mission. Shown in Figure 2.2.2.5-1 is a time-phased program for development of the technology required to conduct the TDM, and the schedule of activities required for either NASA or a TDM contractor to implement the TDM. The figure highlights AXAF, OMV and Space Station program milestones, and presents the sequence of AXAF maintenance and repair activities; i.e., ground developments, STS and Space Station validations that will be conducted to prepare to conduct TDM 2. Also shown on the bottom of Figure 2.2.2.5-1 are the TDM implementation operations leading up to the demonstration mission, tentatively set for 1994. The TDM preparation activities are actually time-phased to enable a "first capability" in 1992 to cover an early failure of AXAF.

### 2.2.2.6 Servicing Benefits at Space Station

The detailed definition/analysis of the AXAF mission conducted by the study team led to a belief that servicing at the Space Station when feasible, will offer many benefits over that provided by using the STS in a role for which it was not primarily designed. The Space Station will offer many advantages, based on STS servicing experience, for extensive servicing operations on complex satellites like AXAF. First, use of Space Station for servicing activities provides relief to the STS, allowing it to focus on its primary "transportation" role. Space Station provides a larger crew dedicated to the M&R activity and with time available immediately prior to the M&R mission to train and polish procedures. The OMV is available, on site, for retrieval and deployment and can be refueled between usages. Repair operations are not time constrained and more power, propellant, tools, materials, and computation and data processing capability are available on Space Station, providing more real time flexibility to handle unplanned contingency situations. Finally, Space Station costs to provide these advantages are minimized because of the use of flight proven/standardized tools, procedures, and interfaces.

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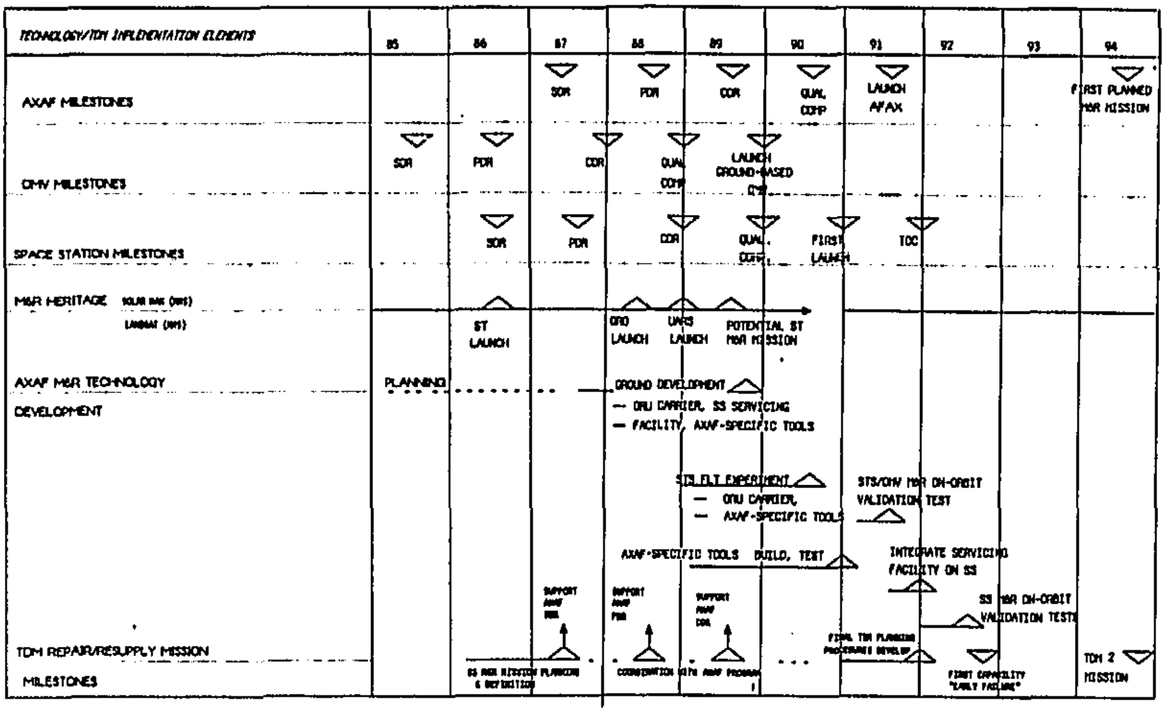


*Figure 2.2.2.5-1 Technology Development Phasing*

### 2.2.3 Satellite Servicing Support Area Assembly - TDM 3

#### 2.2.3.1 TDM Definition

This TDM demonstrates the servicing capability of Space Station modification. As previously stated, this servicing demonstration is one of the three MSFC identified areas of general servicing interest. The specific task entails modifying the Space Station by adding the satellite servicing support area to an assembled Space Station. The servicing elements to be added include: a satellite servicing hangar (cylindrically shaped, 30 feet by 70 feet), a storage facility (similar shape, scaled down to 15 feet by 30 to 50 feet), a fluid storage/transfer depot, and a berthing station for OMV.

The mission is designed to enable transport of all assembly elements to the Space Station in two STS flights. On the first flight, all materials for a service strongback support structure, the service hangar and the OMV berthing mechanism are loaded in two STS cargo canisters, transferred to Space Station, and deployed with the SSRMS to berthing ports in close proximity to the assembly location. The cargo canisters were included to allow rapid removal of the assembly materials from STS, freeing it for return to earth, and to enable temporary storage of the assembly materials. The assembly is projected to require a significant amount of time and the container thus resolves storage problems for both the STS and the Space Station. This container is also used in TDM 4, and could be used in many TDM scenarios to return residuals to earth when the mission is completed. The storage facility and fluid storage/transfer depot are delivered with the second STS flight.

#### 2.2.3.2 Pre-Mission Tasks

Prior to initiation of this TDM, certain top-level ground based and Space Station tasks must be completed and validated.

Ground-based mission preparation tasks will include the design, development, and production of all servicing area elements, such as the storage canister, servicing strongback, RMS track, servicing facility, fuel depot, OMV berthing ring, servicer storage facility, and all associated cabling, interfaces and control stations. Planning and scheduling must be completed for STS delivery of all elements and the tools required for assembly of the service area. Procedures for assembly will be generated, tested, and extensive crew training will be conducted in all facets of the assembly process. Assembly procedures will include canister transfer from the STS to Space Station, canister berthing to the assembly support area, strongback deployment and attachment, latch verification, storage facility deployment and attachment, fuel depot deployent and attachment, berthing ring deployment and attachment, cabling (electrical, fluid) attachment and connection, and comprehensive testing procedures of all assembled components prior to use.

Space Station based activities will include: the receipt of the servicing area elements and mission specific assembly tools, the attachment of the staging area interface, and also the development of assembly simulation exercises which will be conducted prior to initiation of the TDM.

### 2.2.3.3 Mission Activities

Prior to assembly the first STS flight carrying two cargo canisters will dock at the Space Station. These canisters will contain the strongback structure, OMV berthing ring, and the servicing facility components. Table 2.2.3.3-1 is the mission activity sequence timeline. After the docking sequence is complete, and the payload bay doors are open, the STS RMS will grapple the staging area structure and transfer it to the Space Station RMS (SSRMS). The SSRMS will then transport the staging area structure to the end of the Space Station structure and latch it into place. The SSRMS is, of course, operated by an IVA astronaut in SSMC. EVA astronauts will visually verify the connections. The SSRMS will be returned to the STS and grapples the first cargo canister, containing the stowed strongback structure and OMV berthing ring, from the STS RMS. Whenever any cargo is unloaded from the STS, the STS RMS will grapple it, remove it from the cargo bay, and transfer it to the SSRMS. In no case will the SSRMS directly remove cargo from the STS. The canister is then transferred to the recently installed staging area by the SSRMS and attached to the side of the staging area. The SSRMS returns to the STS and the procedure is repeated for the second canister containing the servicing facility components. Berthing the canisters to the staging area provides two distinct advantages: First, it allows the STS to return to earth and not wait for the assembly process to be completed and, secondly, it allows for the storage of necessary equipment at the assembly site. The canisters will be constructed to protect the contents from the space environment.

When the actual assembly process is started, EVA astronauts will be required to visually verify all connections and latch-ups. If this requirement is deleted the assembly time could be completed in a shorter period of time, as EVA astronauts will be limited to 6 hours of EVA time per day.

Phase 1 of the Service Support Area Assembly is illustrated in Figure 2.2.3.3-1. The first deployable service strongback support element is being removed from the first cargo canister by a dual-armed, remotely operated SSRMS. The SSRMS is already installed on a tracked system that enables the SSRMS full access of the Space Station. The support element is then deployed by RMS teleoperation and attached to the nucleus of the Space Station. The automatic alignment, mating and latching process is monitored by EVA astronauts in close proximity, and manual assist will be provided as appropriate. These support elements are 30 feet long. Five sections are connected to form a 150 foot long support structure.

The stowed strongback in the canister is deployed (opened) by the SSRMS once it is removed from the canister and prior to attachment to the Space Station structure.

Table 2.2.3.3-1 Mission Activity Sequence

| Event | Time | Elapsed Time |
|---|---|---|
| First STS docks to SS | 1 hr | 1 + 00 |
| Payload bay doors open | 15 min | 1 + 15 |
| STS RMS lifts staging area structure from cargo bay and transfers structure to SS RMS | 1 hr | 2 + 15 |
| Staging area transported by SS RMS along SS track to servicing area at SS interface | 1 hr | 3 + 15 |
| SS RMS used to berth staging area to SS interface | 6 hr | 9 + 15 |
| Latch-up of staging area to SS visually verified by EVA crew | 1 hr | 10 + 15 |
| SS RMS returns to STS | 15 min | 10 + 30 |
| STS RMS lifts canister containing stowed strongback structure, OMV berthing ring from cargo bay and transfers canister to SS RMS | 30 min | 11 + 00 |
| Canister is transferred to staging area and attached to side of staging area | 2 hr | 13 + 00 |
| Repeat above procedures for canister containing servicing facility components | 2 + 30 | 15 + 30 |
| STS is now empty and free to return to earth | | |
| SS RMS opens canister | 1 hr | 16 + 30 |
| SS RMS removes one strongback section from canister and assists deployment | 3 hr | 19 + 30 |
| SS RMS travels to end of staging area | 1 hr | 20 + 30 |
| Deployed strongback section is positioned/latched at end of staging area | 6 hr | 26 + 30 |
| Latch-up visually verified by EVA crew | 1 hr | 27 + 30 |

Table 2.2.3.3-1 Mission Activity Sequence (Cont)

| Event | Time | Elapsed Time |
|---|---|---|
| SS RMS returns to canister/removes second strongback section and assists deployment | 3 hr | 30 + 30 |
| SS RMS travels to end of first deployed strongback | 1 hr | 31 + 30 |
| Second strongback section is positioned/ latched onto first | 6 hr | 37 + 30 |
| Latch-up visually verified by EVA crew | 1 hr | 38 + 30 |
| Procedure is repeated for three remaining strongback sections | 33 hr | 71 + 30 |
| SS RMS returns to staging area | 1 hr | 72 + 30 |
| RMS and EVA crew remove cabling from canister and move down along strongback attaching cabling at appropriate locations | 12 hr | 84 + 30 |
| Checkout cabling and systems | 12 hr | 96 + 30 |
| SS RMS removes OMV berthing ring from canister | 1 hr | 97 + 30 |
| SS RMS moves down strongback and attaches berthing ring at appropriate location/connect cabling to berthing ring | 6 hr | 103 + 30 |
| SS RMS returns to staging area/opens servicing facilities canister | 1 hr | 104 + 30 |
| SS RMS removes servicing facility base truss from canister. | 30 min | 105 + 00 |
| SS RMS moves down strongback, positions base truss at appropriate interface point and rotates base truss into docking position | 4 hr | 109 + 00 |
| SS RMS docks base truss to strongback | 2 hr | 111 + 00 |
| EVA crew visually verifies latch-up of base truss to strongback | 1 hr | 112 + 00 |

Table 2.2.3.3-1 Mission Activity Sequence (Cont)

Time Sequence for TDM3

| Event | Time | Elapsed Time |
|---|---|---|
| SS RMS returns to staging area and removes first section of servicing facility track/truss. | 1 hr | 113 + 00 |
| SS RMS moves to servicing facility location. | 1 hr | 114 + 00 |
| SS RMS rotates track/truss into attachment position to base truss. | 4 hr | 118 + 00 |
| SS RMS attaches first section to base truss. | 2 hr | 120 + 00 |
| EVA crew visually verifies latch-up | 1 hr | 121 + 00 |
| Procedure is repeated for the four remaining sections. | 54 hrs | 175 + 00 |
| SS RMS returns to staging area and removes rotating carousel from canister. | 1 hr | 176 + 00 |
| SS RMS moves carousel down strongback and attaches carousel to base truss attachment points. | 2 hr | 178 + 00 |
| SS RMS returns to staging area and removes cradle assembly from canister. | 1 hr | 179 + 00 |
| SS RMS transports cradle to servicing facility and attaches cradle into track. | 2 hr | 181 + 00 |
| Repeat procedure for second cradle. | 3 hr | 184 + 00 |
| SS RMS returns to staging area. | 30 min | 184 + 30 |
| SS RMS and EVA crew remove servicing facility utility cabling. | 4 hr | 185 + 30 |
| EVA crew connects utility cabling to servicing facility and strongback cabling. | 4 hr | 189 + 30 |
| Checkout servicing facility subsystems. | 6 hr | 195 + 30 |
| Second STS docks to SS | 1 hr | 196 + 30 |
| Cargo bay doors open. | 15 min | 196 + 45 |

Table 2.2.3.3-1 Mission Activity Sequence (Concl)

Time Sequence for TDM3

| Event | Time | Elapsed Time |
|---|---|---|
| STS RMS lifts fuel storage depot module from cargo bay and transfers to SS RMS. | 1 hr | 197 + 45 |
| SS RMS transports fuel depot to strongback. | 1 hr | 198 + 45 |
| SS RMS positions fuel depot at appropriate interface point and rotates fuel depot into docking position. | 4 hr | 202 + 45 |
| SS RMS docks fuel depot to strongback. | 2 hr | 204 + 45 |
| EVA crew visually verifies latch-up of fuel depot to strongback. | 2 hr | 205 + 45 |
| EVA crew connects fuel depot utility cabling to strongback cabling. | 6 hr | 211 + 45 |
| Checkout fuel depot subsystems. | 6 hr | 217 + 45 |
| SS RMS returns to service crew. | 30 min | 218 + 15 |
| STS RMS removes service storage module from cargo bay and transfers to SS RMS. | 1 hr | 219 + 15 |
| SS RMS transports servicer storage modules to strongback and positions service storage for docking to strongback. | 4 hr | 223 + 15 |
| SS RMS docks servicer storage to strongback. | 2 hr | 225 + 15 |
| EVA crew visually verifies latch-up. | 1 hr | 226 + 15 |
| EVA crew attaches servicer storage utility cabling to strongback cabling. | 4 hr | 230 + 15 |
| Checkout servicer storage subsystems. | 6 hr | 236 + 15 |
| SS RMS returns to staging area/removes empty canister and transports it back to STS. (Only done if canister is to return to earth). | 3 hr | 239 + 15 |
| SS RMS transfers empty canister to STS RMS canister back into STS cargo bay. | 1 hr | 240 + 15 |
| EVA crew services canister for return trip. | 2 hr | 242 + 15 |
| Repeat above procedure for 2nd canister | 6 hr | 248 + 15 |

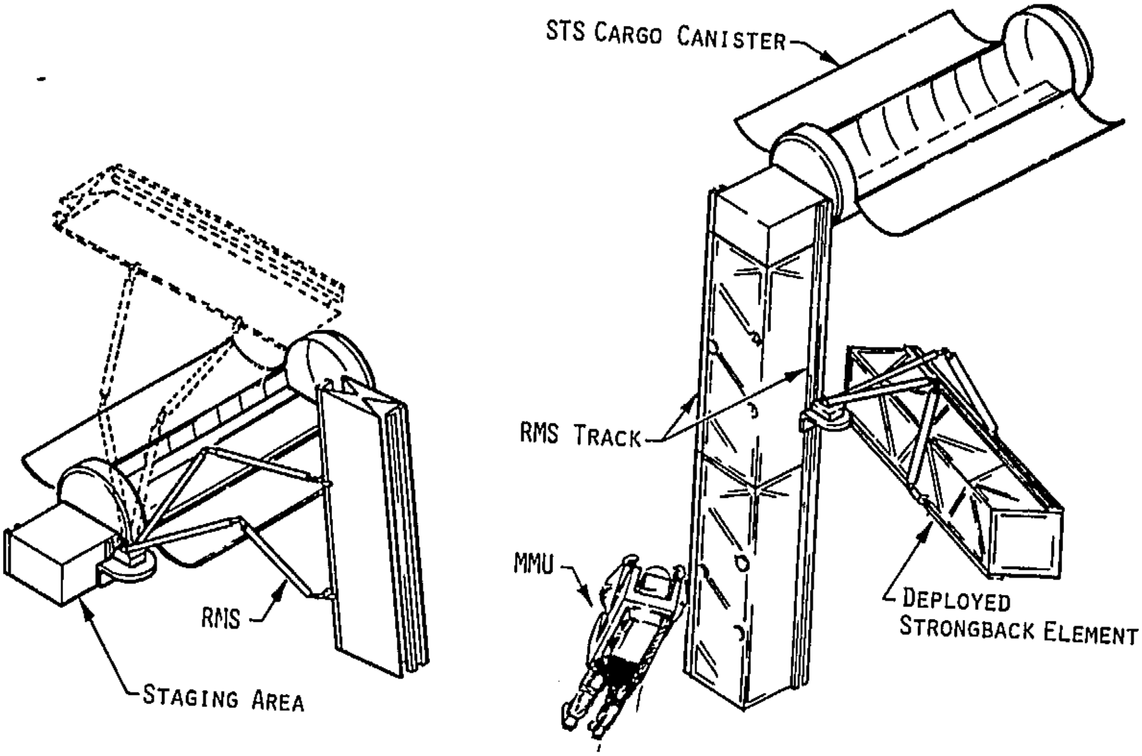


*Figure 2.?.3.3-1   Service Support Area Assembly - Phase 1*

The second strongback section is removed from the canister and deployed, in a similar manner as the first and transported to the end of the first attached strongback section. The SSRMS is traveling on a tracked system and the newly attached strongback section allows the RMS to transit the entire length on a continuous compatible track.

The remaining three strongback sections are deployed, attached, and EVA astronauts verify the connections of each section.

Next, the astronauts, with help from the SSRMS, remove the necessary cabling from the cargo canister. The cabling is attached at appropriate locations as necessary on the entire length of the assembled strongback. A complete checkout of the cabling is then conducted to ensure proper performance.

The SSRMS returns to the canister and grapples the OMV berthing ring. The SSRMS transports the berthing ring down the length of the strongback and attaches it at the appropriate location. EVA astronauts verify the connection, attach the cabling interface, and the berthing ring is checked-out for proper operation.

The next element assembled in this mission is the servicing facility. Assembly of this facility is represented in Figure 2.2.3.3-2. The second cargo canister is shown loaded with servicing facility assembly elements and these elements are removed and transferred to the assembly area. The assembly operations are conducted with the coordinated efforts of the SSMC (mission control) RMS operator operating the dual arm, tracked manipulator, and supported by astronauts in EVA. The astronauts will use the MMU until relocatable foot restraint supports are available, and will then use foot restraints for improved assembly support capability, sans MMU.

The RMS will position and dock the servicing hangar base truss to the strongback. EVA crew will visually verify latch-up. The RMS will return to the staging area and remove a section of the servicing hangar track/truss. The RMS will attach the track/truss to the base truss, with an EVA crew to visually verify latch-up. This procedure is repeated for the remaining sections. The RMS will then install the carousel mechanism on the base truss, and the cradle support elements on the servicing track. A hard cover will be assembled around the servicing facility using the RMS with astronaut EVA support.

Finally, the servicing facility utility cabling is removed from the canister, connected to the servicing facility, interfaced with the strongback cabling, and the entire servicing facility is operationally checked-out. Subsequently, the second STS delivery mission is completed, bringing the remaining service support area elements, the storable fluid depot and servicer storage hangar, to the Space Station.

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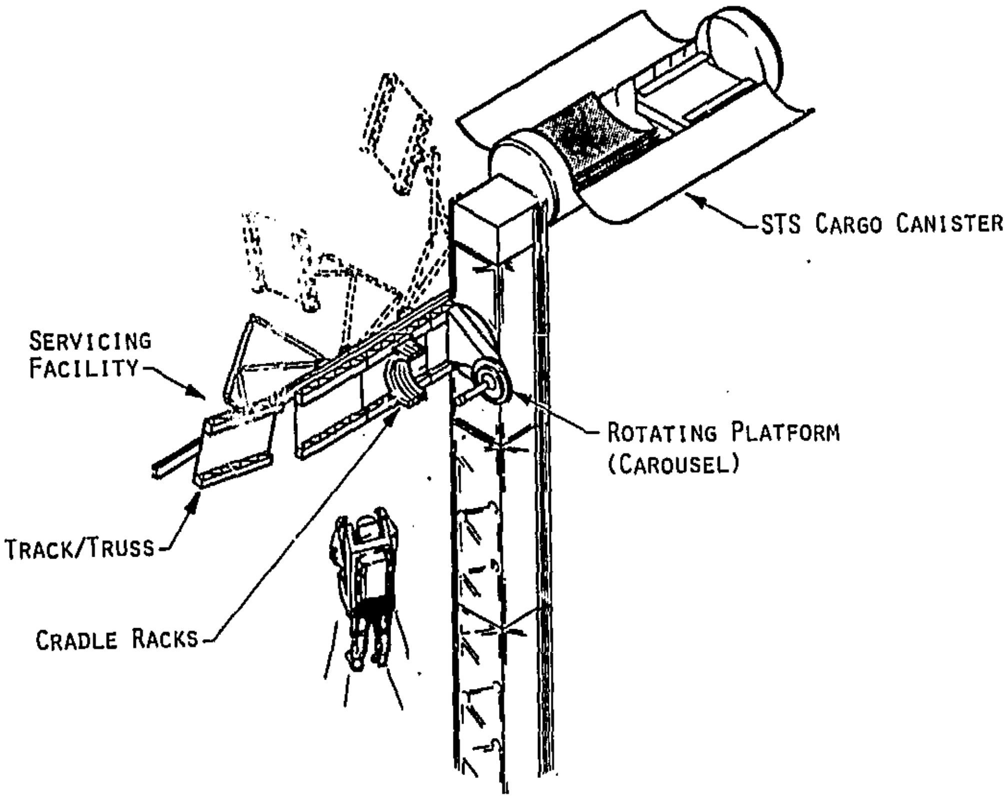


*Figure 2.2.3.3-2 Service Support Area Assembly - Phase 2*

This next phase of this Space Station modification TDM is illustrated on Figure 2.2.3.3-3. The shielded service hangar and OMV berthing ring are shown attached to the service strongback support structure. The STS is represented as docked at Space Station with the second cargo load for this TDM. The dual-armed SSRMS has grappled the servicing storage facility, (assembled on earth as it is sized to be cargo bay compatible), and will transfer it to an assembly point on the service support structure. The storage hangar will be aligned for mating by the SSRMS operator, and latched and checked by supporting astronauts in EVA. The fuel depot, also shown in the STS, will be transferred similarly to an assembly point just above the OMV berthing ring, and securely attached to the strongback support area.

Following attachment of each service element to the strongback, the interface connections between elements and the strongback will be made. Power, data handling, and fluid transfer connects will be made by astronauts to provide required Space Station support to each of the servicing elements.

This completes a top level representation of the TDM 3 activities. Presented in Figure 2.2.3.3-4 is a conceptual Space Station satellite servicing support area containing many of the support elements considered requisite to enable servicing operations at a fully developed early Space Station.

The support area is connected to the Space Station by a strongback support element, which provides distancing from the nucleus of the station. As shown, the servicing support area contains a central servicing facility, a fuel depot, a Space Station manipulator capable of translation throughout the area, an Orbital Maneuvering Vehicle (OMV) berthing port and a servicer/module storage facility.

The two empty canisters can either be retained at the Space Station for storage space or can be placed in the STS cargo bay and returned to Earth for reuse in follow-on TDMs.

### 2.2.3.4 Post-Mission Tasks

Following completion of the assembly on the Service Support Area, several post mission tasks will remain to be completed to retain an orderly and efficient Space Station servicing area.

Empty assembly canisters will be returned to Earth via the STS or used to provide shielding for servicers and replacement modules. System and subsystem check-outs will be performed on the fuel depot, servicing facility and servicer storage facility. All equipment used on this mission (EMU, MMU) will be recharged, refueled, checked out and stored properly to be ready for future use. A review and update of the mission operation procedures will be conducted and revised for similar future operations.

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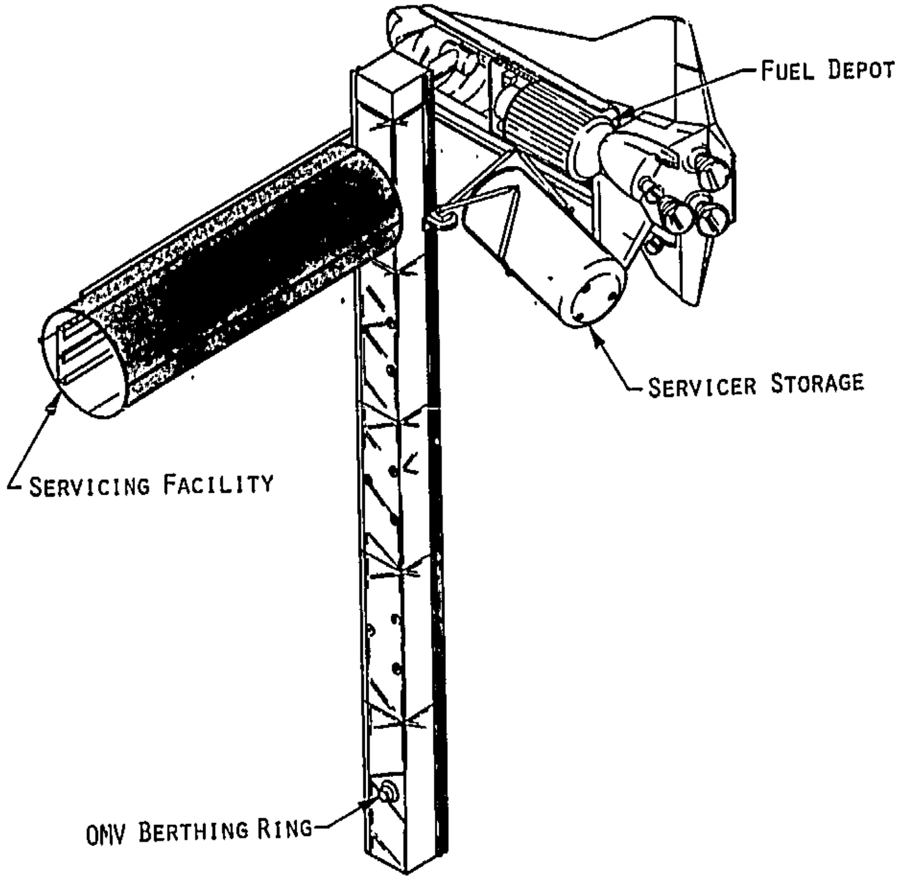


*Figure 2.2.3.3-3   Service Support Area Assembly - Phase 3*

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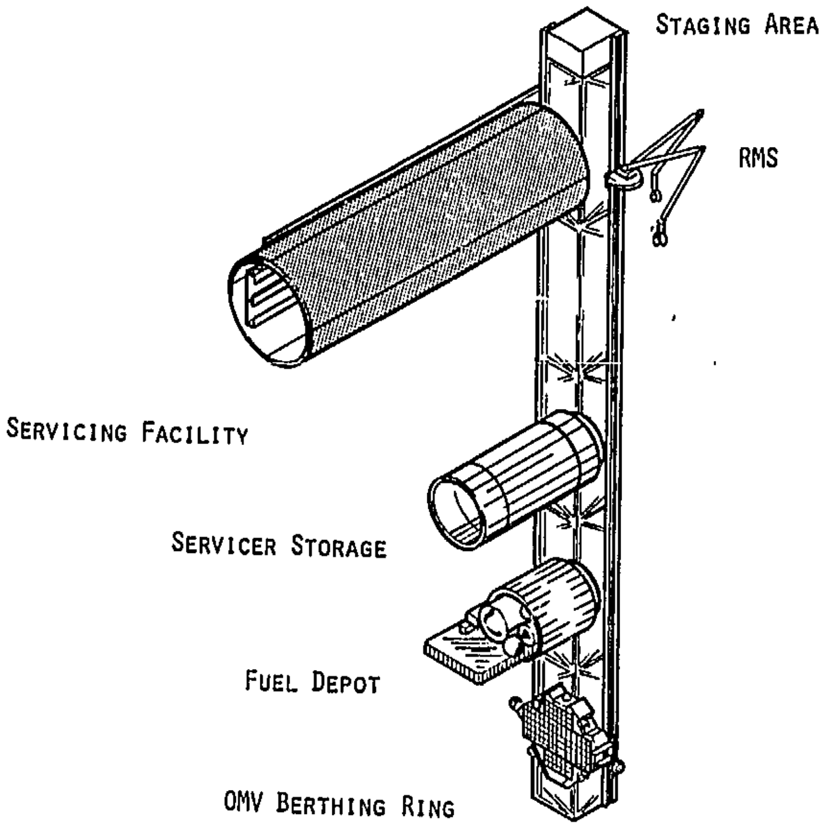


*Figure 2.2.3.3-4 Service Support Area Assembly*

2.2.3.5 Technology Assessment

Technology available today includes packaging techniques for structural deployment of space structures, development of onorbit structural assembly approaches, and experimentation using existing manipulator capability on the STS.

Ongoing technology development planned for the Space Station nucleus includes: explorations in the area of structural connectors, fluid quick disconnects, fluid transfer/storage, work platforms and other areas with direct application to this Space Station Assembly TDM.

Technology voids for this TDM appear to be limited, and perhaps non-existent.

2.2.3.6 Issues and Trades

The operational analyses done for this development mission led to the identification of top-level issues that introduce candidate trade studies for continued refinement of this TDM. These issues are highlighted below.

The structural approach to attaching a service support area to the Space Station requires a series of trade studies to examine the alternatives of providing deployable assembly elements, versus conducting more extensive erection assembly operations, requiring substantial increases in EVA operation time.

Structural rigidity trade considerations relate to the degree of rigidity required for the service support area. High rigidity requirements increase weight and complexity.

Isolation system trade considerations relate to the degree of isolation required for the servicing area, to minimize impact on scientific and commercial payloads attached to the Space Station. Increased isolation of the servicing area will reduce docking/berthing, closing and impact requirements, will will increase design complexity and cost.

Further trade studies will be essential to assess the benefits of thermal, radiation, and micrometeoroid protection for elements of the servicing area, including the servicing facility, and servicer/module storage areas.

Operation and location of the fuel depot suggest trades related to fully automated versus EVA supported fuel handling. The fuel depot location will require trades relating to the need for proximity of operations versus safety and contamination avoidance.

OMV fuel storage issues suggest trades on where fluids (fuel and pressurants) should be stored. Transfer operations suggest trades related to tank changeout versus fluid transfer.

### 2.2.4 Assembly of Large Spacecraft - TDM 4

#### 2.2.4.1 TDM Definition

The Large Spacecraft Assembly mission addressed the second principal servicing category identified for Phase 2 of the Satellite Servicing study. Onorbit assembly of large spacecraft at the manned Space Station will add a new dimension to considerations for scientific and commercial use of space. Several current large spacecraft concepts, presently in various stages of planning, were considered as candidates for this mission. The Large Deployable Reflector (LDR) appeared to be the best defined future mission of this type and was selected for that reason. The onorbit assembly of LDR also appeared to offer significant technology challenges and would add additional breadth and depth to definition of Space Station servicing requirements and accommodation needs.

The general outline of this TDM is illustrated in Figure 2.2.4.1-1. The detailed definition of the mission was outlined in four top level activity phases. The first activity grouping includes those mission events related to delivery of the LDR spacecraft/scientific instrument package and, the structural and reflector elements of the mirror assembly. Current planning estimates indicate that all LDR assembly components can be delivered to the Space Station in two Shuttle orbiter missions.

The second phase involves assembly of the 20 meter (diameter) mirror assembly on the Space Station, and attachment of a 20 meter long sunshade to the mirror, using the SSRMS and an RMS-mounted servicing work station (to support EVA) to conduct the assembly. The final two stages include deployment of the assembled LDR to its operational orbit using OMV, and the final task of returning OMV to the Space Station for refurbishment and reberthing.

#### 2.2.4.2 Pre-Mission Tasks

Prior to the initiation of TDM 4 certain ground and space based activities must be completed.

Ground based mission preparation tasks include the design, development, test and delivery of the resources required to accomplish the mission. These resources include mission specific tools/support equipment; such as power ratchet tools, work platforms, and miscellaneous assembly tools; and the LDR elements; such as mirror segments, the backup truss, the instrument package, the spacecraft secondary mirror and sunshade elements.

Procedures for specific mission activities must be generated and tested. Some representative procedures would include: transfer of LDR elements from the staging area to the assembly port, LDR assembly (including primary clusters, secondary mirror/support assembly, and sunshade) and checkout, OMV/LDR mating and orbital transfer, and ground training.

- DELIVER LARGE DEPLOYABLE REFLECTOR (LDR) STRUCTURAL ELEMENTS AND REFLECTOR SEGMENTS TO SPACE STATION IN TWO ORBITER MISSIONS.
- ASSEMBLE LDR ON SERVICE STRUCTURE STRONGBACK USING MMU AND STATION RMS/WORK PLATFORM.
- DEPLOY LDR TO OPERATIONAL ORBIT WITH OMV.
- RETURN OMV TO SPACE STATION AND REFURBISH.

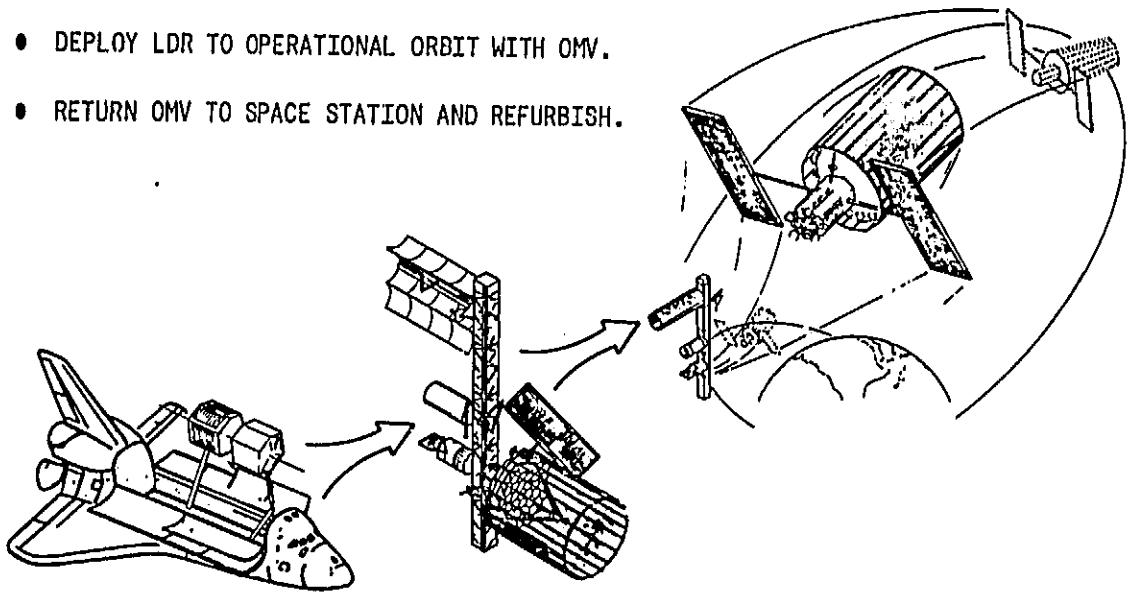

*Figure 2.2.4.1-1 TDM 4 - Assembly of Large Spacecraft*

At the Space Station, the mission resources must be received and temporarily stored in preparation for initiation of the TDM. In addition, the Space Station servicing strongback must be prepared for the attachment of the initial LDR elements (spacecraft, instrument package). This would entail the attachment of a rotating ring onto a designated berthing port on the strongback. Space Station based training would have to be completed, and OMV fuel would need to be received and stored.

### 2.2.4.3 Functional Flow

The functional flow for the assembly of the large deployable reflector is shown in Figure 2.2.4.3-1. Phase 1 entails having the first STS flight dock at the Space Station, mating the spacecraft and science instrument package in the cargo bay, berthing the mated spacecraft and scientific instrument package on the servicing support area strongback and conducting operational tests, and attaching the LDR primary mirror segment clusters to the scientific package. Also shown in the figure are the required elements needed to complete a particular segment of the phase. Another method of transporting the spacecraft/scientific instrument package would be in a canister, already mated.

Phase 2 consists of; the docking of the second STS to the Space Station; removal of the LDR secondary mirror and support assembly canister from the cargo bay, and berthing of the canister to the staging area; attachment of the secondary mirror and support assembly to the LDR structure; test of the primary and secondary mirror assemblies; attachment of the cylindrical sunshade elements; and subsystem checkout and operational validation.

Phase 3 is the transportation of the assembly to orbit including; the checkout and verification of OMV operability; transfer and fueling of the OMV; transfer and mating of the OMV with the LDR; the actual orbit transfer operations; and return and refurbishment of the OMV.

### 2.2.4.4 Activity Sequence

The activity sequence timeline is shown in Table 2.2.4.4-1. The first STS arrives, is docked at the Space Station, and the cargo bay doors are opened. The STS RMS grapples and lifts the canister containing the spacecraft/scientific instrument package, secondary mirror and support assembly, sunshade assembly, and nine primary mirror segment clusters from the cargo bay and transfers it to the SSRMS. The canister is transferred and attached to the LDR assembly area. The STS is empty and free to return to Earth. When the second STS arrives with the second canister carrying the remaining ten primary segment clusters the procedure is repeated again.

**First STS Flight Docks at SS**
- Universal Docking System

**Spacecraft & Science Instruments Mated In Cargo Bay**
- Shuttle RMS
- RMS Control Console

**Spacecraft & Scientific Instruments Berthed on Servicing Support Area Strongback; Conduct Tests**
- RMS/RMS Track
- RMS Control Console
- RMS/Work Platform
- EMU
- Berthing System
- Alignment Equipment
- Attachment Hardware
- Communications
  - CC TV
  - Audio

**Attach LDR Primary Mirror Segment Clusters to Scientific Package**
- RMS/RMS Track
- RMS Control Console
- RMS/Work Platform
- Assembly Tools & Hardware
  - Work Platform
  - Power Ratchet
  - Miscellaneous Tools
- EMU
- Communications
  - CC TV
  - Audio
  - Helmet-Mounted CRT Display

*Functional Flow Phase 1 - Spacecraft Package and Primary Mirror Assembly*

**Second STS Flight Docks to SS**
- Universal Docking System

**Remove LDR Secondary Mirror & Support Assy Canisters from Cargo Bay; Berth to Staging Area**
- RMS/RMS Track
- RMS Control Console

**Attach Secondary Mirror & Support Assy to Evolving LDR**
- RMS/RMS Track
- RMS Control Console
- RMS/Work Platform
- EMU
- Assy Tools & Hardware
  - Power Ratchet
  - Misc
- Communications
  - CC TV
  - Audio
  - Helmet-Mounted CRT Display

**Test LDR Primary & Secondary Mirrors**
- RMS/RMS Track
- RMS Control Console
- RMS/Work Platform
- EMU/MMU
- Communications
  - SSMC
  - SSGC

**Attach Cylindrical Sunshade to LDR**
- RMS/RMS Track
- RMS Control Console
- RMS/Work Platform
- EMU
- Communications
  - CC TV
  - Audio
- Attachment Tools & Equipment

**Perform Subsystem Checkout & Operational Validation**
- EMU/MMU
- Communications
  - SSGC
  - SSMC
  - Audio
  - CC TV

*Functional Flow Phase 2*

*Secondary Mirror and Sunshade Assembly*

**Checkout/Verify OMV Operability**
- RMS/RMS Track
- RMS Control Console
- OMV Control Console
- Power Supply & Controls
- Checkout Eqpt

**Transfer & Dock OMV to Fuel Depot; Fuel OMV**
- RMS/RMS Track
- RMS Operations Console
- OMV Control Console
- Berthing System
- Alignment Eqpt
- Communications
  - CC TV
- Power Supply & Controls
- Propellant Transfer Gaging Eqpt
- Fuel Transfer Control Console

**Transfer & Mate OMV with LDR**
- RMS/RMS Track
- RMS Operations Console
- RMS/Work Platform
- OMV Control Console
- Berthing System
- Alignment Eqpt
- Power Supply & Controls
- Communications
  - CC TV
  - Audio
  - SSGC

**Conduct Orbit Transfer Operations**
- OMV Control Console
- Communications
  - SSGC

**Return OMV to Station & Refurbish**
- OMV Control Console
- RMS/RMS Track
- RMS Control Console
- Servicing Facility
- Communications
  - CC TV
  - SSGC
  - SSMC

*Functional Flow Phase 3 - Orbital Transfer Operation*



*Figure 2.2.4.3-1*

Table 2.2.4.4-1 Activity Sequence Timeline for LDR Assembly

Time Sequence for TDM4

| Event | Time | Elapsed Time |
|---|---|---|
| Dock 1st STS to SS | 1 hr | 1 + 00 |
| Cargo bay doors open | 15 min | 1 + 15 |
| STS RMS lifts canister containing spacecraft/scientific instrument package, secondary mirror and support assembly, sunshade and support assembly and 9 primary mirror segment clusters from cargo bay and transfers canister to SS RMS. | 1 hr | 2 + 15 |
| Canister transferred to LDR assembly area and attached to strongback | 2 hr | 4 + 15 |
| STS is now empty and free to return | | |
| Repeat above procedure when 2nd STS arrives carrying 2nd canister with the remaining 10 primary segment clusters. | 3 + 15 | 7 + 30 |
| SS RMS opens first canister | 30 min | 8 + 00 |
| RMS grapples spacecraft/scientific instrument package, removes it from canister, transports it to LDR assembly area and mounts it to rotating ring located on SS strongback. | 2 hr | 10 + 00 |
| EVA crew visually verify connection secure | 1 hr | 11 + 00 |
| Conduct test on spacecraft/scientific instrument package | 6 hr | 17 + 00 |
| RMS returns to canister, removes primary mirror cluster and transports it to LDR assembly area | 30 min | 17 + 30 |
| EVA crew deploy the support truss mounted on the back of the primary mirror cluster NOTE: Each segment cluster will consist of three elements, all pre-assembled on earth. The three elements are: <br>- hexagonal mirror (7 mirror elements) <br>- support truss <br>- mirror alignment activators (3 for each mirror element) | 1 hr | 18 + 30 |

Table 2.2.4.4-1 Activity Sequence Timeline for LDR Assembly (Cont)

Time Sequence for TDM4

| Event | Time | Elapsed Time |
|---|---|---|
| EVA crew attach primary mirror cluster to LDR spacecraft/scientific instrument package and secure it at three attach points | 2 hr | 20 30 |
| Repeat above procedures 18 times for the remainder of the primary mirror clusters. NOTE: The rotatable berthing ring at the assembly site will be controlled by SS crew to aid in the attachment of primary segment clusters. | 63 hr | 83 + 30 |
| RMS moves to canister area and removes the secondary mirror and support structure | 30 min | 84 + 00 |
| RMS transports the secondary mirror and support structure to the LDR assembly area | 30 min | 84 + 30 |
| Deploy secondary mirror support structure | 2 hr | 86 + 30 |
| EVA crew attach secondary mirror and support structure to LDR structure | 2 hr | 88 + 30 |
| RMS moves to canister area and removes initial sunshade element | 30 min | 89 + 00 |
| RMS transports sunshade element to assembly site | 30 min | 89 + 30 |
| EVA crew attach sunshade element to evolving LDR structure NOTE: Each follow-on sunshade element is latched onto the preceding element | 1 + 30 | 91 + 00 |
| Repeat the above procedures for the remainder of the sunshade elements | 36 hr | 127 + 00 |
| RMS moves to canister area and removes solar array | 30 min | 127 + 30 |
| RMS transports solar array to LDR assembly | 30 min | 128 + 00 |
| EVA crew attach solar array to LDR scientific instrument package. | 2 hr | 130 + 00 |
| Repeat above procedures for 2nd solar array. | 3 hr | 133 + 00 |
| Deploy all deployable elements (solar panels, communications masts, etc.) | 30 min | 133 + 30 |

Table 2.2.4.4-1 Activity Sequence Timeline for LDR Assembly (Concl)

Time Sequence for TDM4

| Event | Time | Elapsed Time |
|---|---|---|
| Conduct total subsystem/system checkout/operational validation by SSGC and/or SSMC | 6 hr | 139 + 30 |
| Prepare LDR for orbit transfer (retract deployable elements) | 30 min | 140 + 00 |
| Form transfer stack with OMV and LDR. (Table I) | 2 hr | 142 + 00 |
| OMV transits to desired orbit/releases LDR spacecraft | 1 hr | 143 + 00 |
| Perform an orbit operational checkout of LDR spacecraft | 6 hr | 149 + 00 |
| OMV returns to SS (Table C) | 1 hr | 150 + 00 |
| Refurbish OMV (Table D) | 5 hr ( + refurbishment) | 155 + 00 |

An IVA crewmember operating the SSRMS opens the first canister, grapples the spacecraft/scientific instrument package, removes it from the canister, transports it to the LDR assembly area and mounts it to the rotating ring located on the Space Station strongback. EVA astronauts then visually latch up and conduct testing procedures.

The next activity sequence of the large spacecraft assembly TDM is the assembly of the LDR primary mirror segment clusters and attachment to the LDR spacecraft/scientific instrument element. The STS cargo canister is used in this TDM to transport and store mirror cluster segments during an anticipated lengthy assembly period. The mirror segment clusters have a diameter roughly equal to the diameter of the STS cargo bay. Each cluster is comprised of seven 2-3 feet hexagonal mirrors. Each of these mirrors has a deployable support structure and three actuator mechanisms to enable individual alignment of each mirror, after the entire adaptive mirror system is assembled.

Figure 2.2.4.4-1 outlines transport of a primary mirror cluster (total of 19-20) to the primary mirror assembly area. The mirror cluster assemblies are aligned, attached and checked-out, using the combination of a remotely operated manipulator mechanism and an astronaut on a mobile work station. The work station has movable manipulator foot restraints to provide astronaut stability for this precision assembly operation.

The actual assembly of the mirror cluster segments is the most stressing technical challenge in this TDM. Pre-alignment, then latching and post assembly alignment will be difficult. A software checkout program validating alignment accuracy (following assembly of the mirror segments), will be required. This alignment checkout procedure must be pre-tested on the ground and on the STS prior to initiation of this mission.

Another complex technical challenge relates to the need to retain the mirror segments free from contamination during the entire assembly process.

The next phase of the LDR assembly mission includes attachment of the secondary mirror subsystem to the mirror assembly, and attachment of the sunshade elements. These activities are conducted with a teleoperated SSRMS transporting assembly materials to the LDR, and astronauts performing the assembly operations. The assembly operations will be structured to enable maximum support from a translatable manipulator system. Advanced automation capabilities for the Space Station RMS are highly recommended to support difficult and time consuming assembly tasks and to increase man's productivity in these operations.

Following construction of the sunshade, the two solar arrays are attached, one at a time, to the LDR structure. With these activities completed, the LDR assembly is complete. At this time, the LDR spacecraft and scientific instruments are rechecked, adaptive mirror segments are tested for effective alignment and the LDR is considered ready for transport. At this point the LDR is ready to be transferred into its operational orbit.

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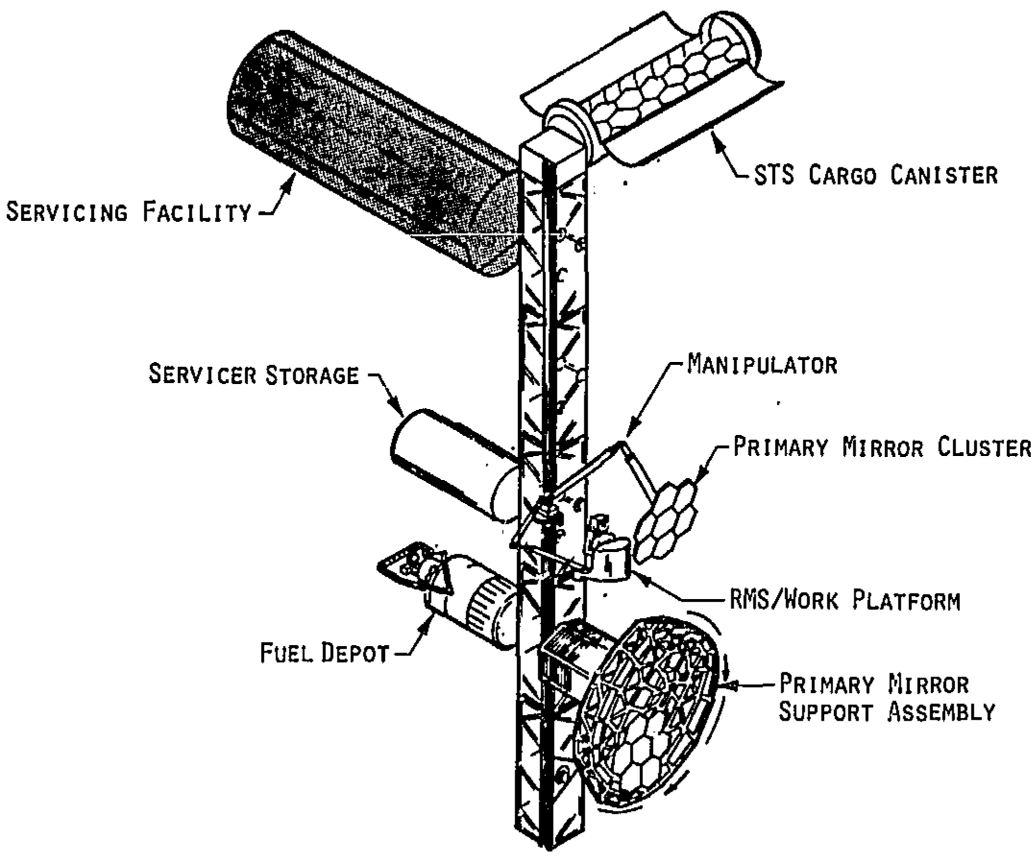



*Figure 2.2.4.4-1 LDR Assembly - Phase 1*

A Space Station mission control crewmember will use an RMS console to move the RMS over to the OMV berthing port and grapple the OMV. The RMS controller will then move the mated and checked-out RMS/OMV to the fuel depot for a remote refueling operation. The OMV is attached to the fuel depot and fueled. The OMV is then transported and mated to the LDR structure.

The OMV/LDR will maneuver away from the Space Station using contamination free proximity operations engines to a distance of 2000 - 3000 feet, to minimize contamination from the plume of the OMV main engines, and complete orbit transfer operations.

After the LDR has been delivered to its operational orbit and operationally tested, the OMV is demated and returns to the Space Station.

This set of activities completes the detailed description of TDM 4, the onorbit assembly of LDR at the Space Station. Conduct of this mission in the late 1990s will demonstrate a significant new servicing capability at the Space Station.

#### 2.2.4.5 Post-Mission Tasks

Following completion of the LDR assembly mission, several postmission tasks remain to be completed. LDR assembly tools and support equipment will be returned to Earth to retain an orderly and efficient Space Station Servicing area. A review and update of the mission operation procedures will be conducted.

At the Space Station, OMV fuel and pressurant tanks must be replenished on a timely basis in addition to the checkout and storage of the EMU, MMU and OMV.

#### 2.2.4.6 Technology Assessment

Technology available today includes tool design, MMU operations, packaging techniques for structural deployment of space structures, and experimentation using existing manipulator capability on the STS.

Ongoing technology development planned for the Space Station nucleus includes: contamination control techniques, work platforms, berthing/docking interfaces, OMV operations, manipulator translation, and other areas with direct application to this TDM. No specific technology gaps exist at this time, with the exception of onorbit adaptive mirror segment assembly techniques.

#### 2.2.4.7 Issues/Trades

The functional analyses of this development mission led to the identification of top-level issues which will serve as candidate trade studies for continued refinement of this TDM.

The first issue pertains to the configuration of the LDR primary segment clusters. There are at least two possible considerations; ground-based assembly, or on-orbit assembly. On-orbit assembly would provide shuttle manifest efficiency but would impose greater EVA (IVA) requirements on the assembly mission. Ground based assembly could allow for the backup truss members to be built in a folded mode which would be deployable on orbit.

The second issue relates to how the segment clusters would be attached to the spacecraft/instrument package. This process might be accomplished with astronauts using a work platform and MMU's or it may be done remotely/automatically. This is a tradeoff that will have to be made once more experience has been gained in such activities.

The material in which the sunshade is composed of is another factor to consider. The construction would depend upon the requirements imposed for thermal, radiation and micrometeoroid protection.

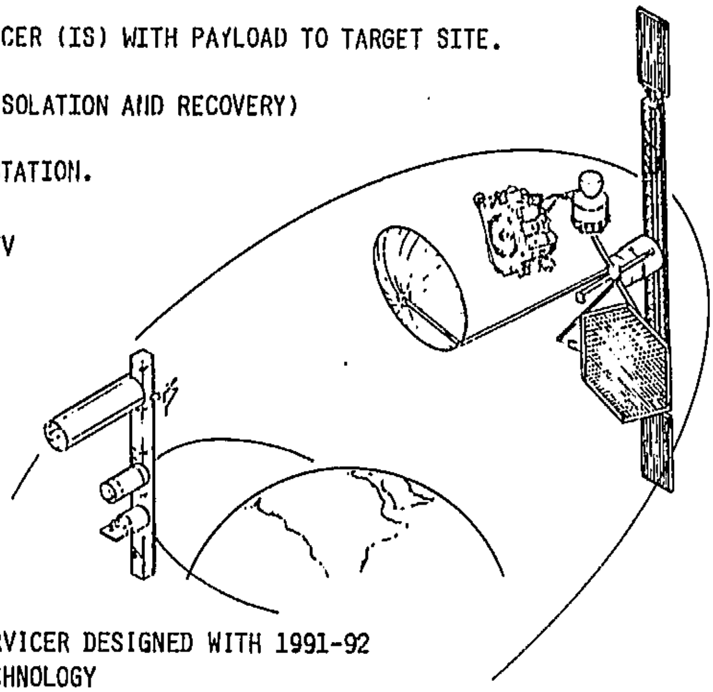
The last issue relates to LDR testing. Various tests will be performed on the LDR. The primary and secondary mirrors will be operated, evaluated and tested for operations within specified tolerances. A total subsystem/system checkout/operational validation will also be done. These tests may be accomplished in their entirety by Space Station Mission Control, or if required, by Space Station Ground Control.

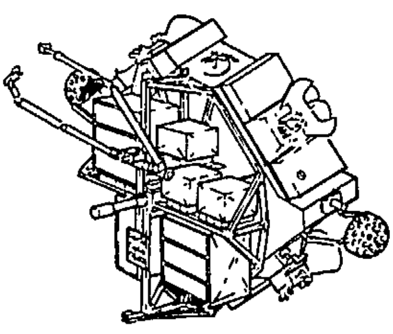
### 2.2.5 TDM 5 - Remote Repair with Intelligent Servicer

NASA MSFC requested that Martin Marietta develop a servicing scenario that would demonstrate increased satellite servicing capability at a mature Space Station. The scenario selected was to conduct a nearly autonomous fault isolation/system restoral operation on a disabled satellite located at the Experimental Geostationary Platform (XGP), in the late 1990s.

An outline of the principal TDM 5 activity sequences is provided in Figure 2.2.5-1. The first activity group, not unlike previously defined TDMs that involve activities remote from Space Station, involves preparation of the orbit transfer equipment. Thus, as shown, an Orbital Transfer Vehicle (OTV), and the OMV and the Intelligent Servicer (IS) are fueled and loaded, mated and deployed from Space Station. The OTV then delivers the "Transfer Stack" to a rendezvous with XGP in GEO, and the OMV and the attached Intelligent Servicer (IS) are separated. The OMV/IS next rendezvous' and docks with the disabled XGP satellite. The IS, conducts a highly automated fault isolation and recovery process, under supervisory control from the ground. When the satellites' operation has been restored and operationally validated, the OMV/IS returns to rendezvous and mate with the OTV. Finally, the OTV returns the Transfer Stack to the Space Station, and all vehicles in the transfer operation are refurbished, reberthed and made ready for the next mission.

- PREPARE INTELLIGENT SERVICER AND OTV/OMV FOR MISSION.
- DEPLOY INTELLIGENT SERVICER (IS) WITH PAYLOAD TO TARGET SITE.
- PERFORM MISSION (FAULT ISOLATION AND RECOVERY)
- RETURN IS/OMV TO SPACE STATION.
- REFURBISH/STOW IS/OMV/OTV





-SERVICER DESIGNED WITH 1991-92 TECHNOLOGY
-DEVELOPED FOR FLIGHT BY 1996-97

*Figure 2.2.5-1 TDM 5 - Remote Repair by Intelligent Servicer*

The Intelligent Servicer is the primary new servicing element in this TDM. A representative dual armed Intelligent Servicer is shown mated to an OMV in Figure 2.2.5-2. The approach used in postulating a servicer for this mission was to: 1) identify relevant servicer technology elements (manipulators, sensors, computer vision, artificial intelligence/expert systems) out to the end of 1991; and 2) integrate appropriate evolving technology into an Intelligent Servicer design that could be developed and flown in 1996-97 to demonstrate the advances in servicing capability.

A functional analysis for TDM 5 is shown in Figure 2.2.5-3. This graphic further identifies the specific activities involved in the three primary phases of TDM 5. Phase 1 includes those activities required to prepare the servicing Transfer Stack, transfer it to the geostationary platform and then separate the OMV and Intelligent Servicer to dock with the inoperative satellite. Phase 2, as shown in Figure 2.2.5-3 outlines the activities connected with the actual repair mission, fault isolation and restoral. Phase 3 includes those activities related to returning the Transfer Stack to the Space Station and refurbishing the reusable vehicles; OTV, OMV and Intelligent Servicer.

An expansion of Phase 2, the actual repair of the malfunctioning satellite at the XGP, is shown in Figure 2.2.5-4. The Intelligent Servicer is first docked at the disabled XGP satellite. The IS is fixed firmly with stabilizer bars, and fault isolation umbilical connections are affected autonomously. This operation is illustrated in Figure 2.2.5-5.

The fault isolation and detection process is initiated with the use of highly advanced artificial intelligence (AI) and manipulator systems operating interactively. The objective of this operation is to understand the work area. Normal operation of the satellite's system(s) has halted and reevaluation of the satellite's configuration must now be accomplished. This is accomplished by comparing the satellite's new configuration with the configuration known prior to the malfunction. Thus, an initial task is to conduct "image understanding" operations using advanced multiple arm manipulators, advanced sensors (proximity, tactile, force moment), 3-D lasers, computer vision systems and color stereo cameras. The new "work station" images are now correlated with system(s) design/malfunction data stored in the AI "expert system". The artificial intelligence systems performs comparative analyses, uses advanced decision-oriented algorithms to isolate the fault(s) and provides recommended restoral actions to a human in supervisory control of the repair operation at SSGC.

Restoral activities are directed by SSGC mission supervisor(s) and the expert system/manipulator system(s) conduct restoral operations including replacement of lowest replaceable unit(s) (LRUs) or malfunctioning/damaged system components, either in the spacecraft or science instrument/payload elements.

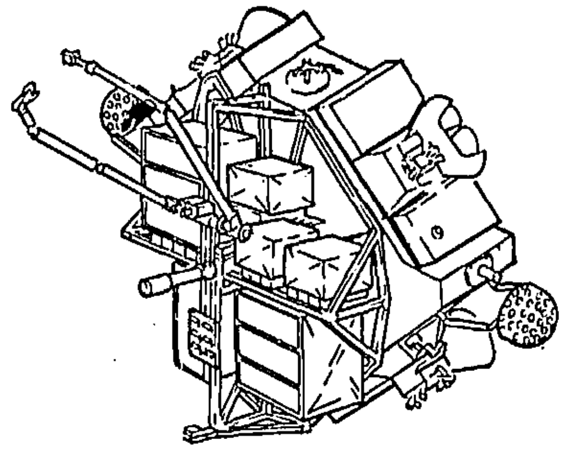


*Figure 2.2.5-2 Intelligent Servicer*

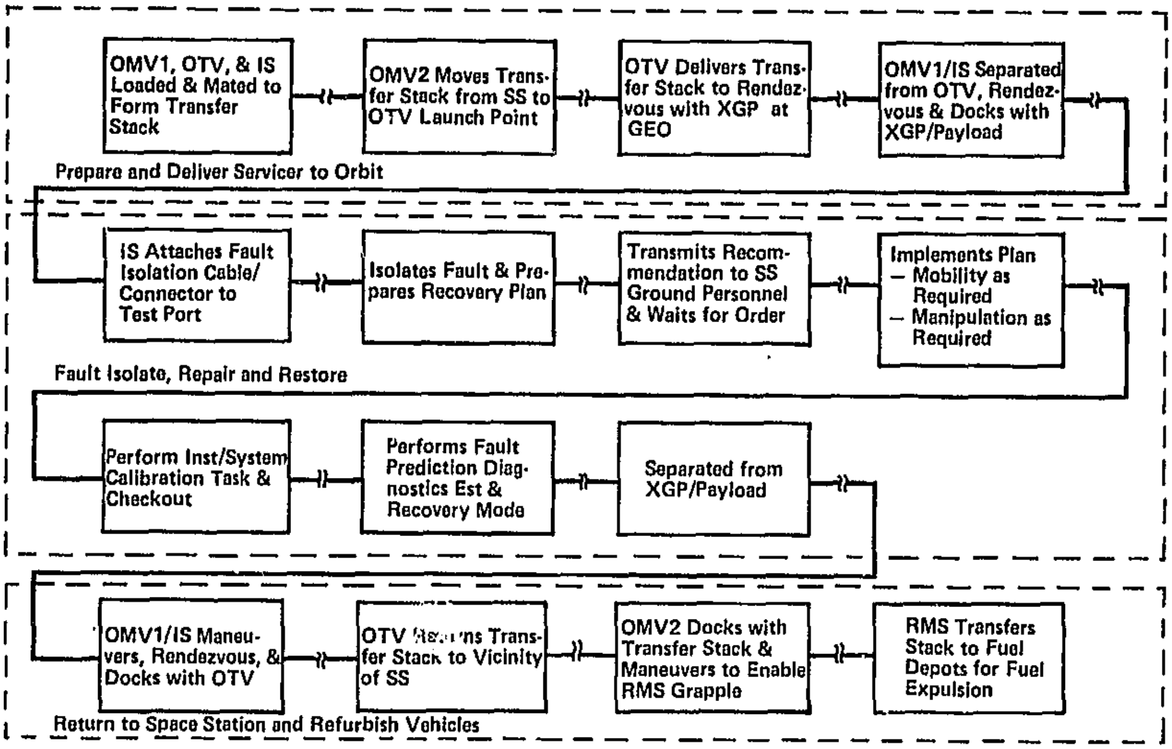



*Figure 2.2.5-3 TDM 5 - Scenario*

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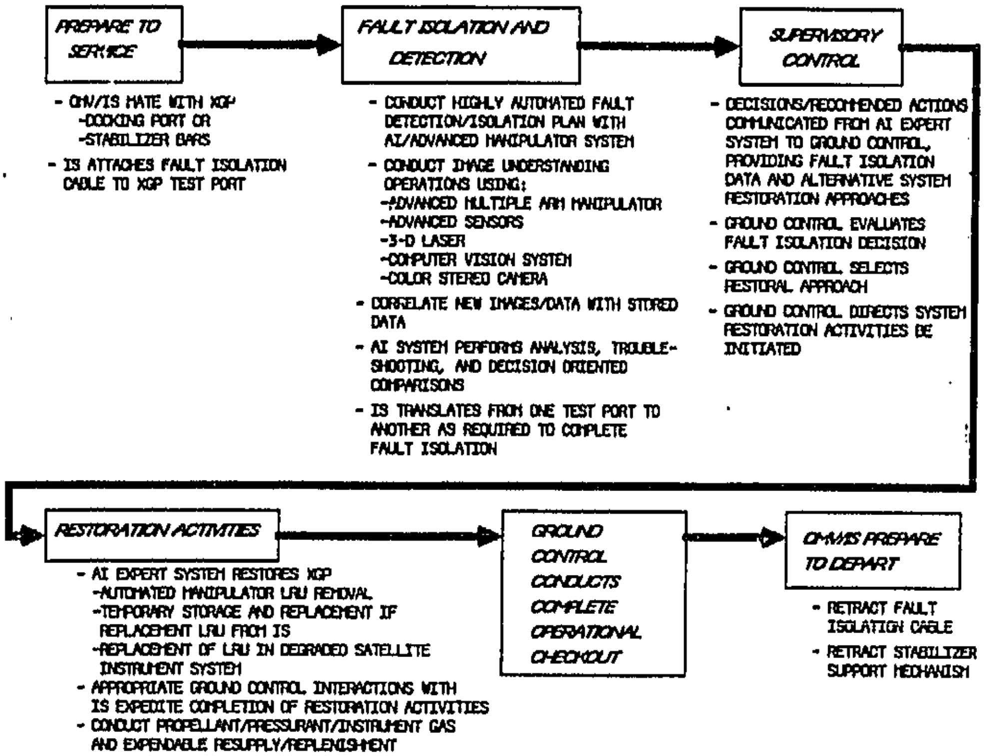


*Figure 2.2.5-4 TDM Repair Events*

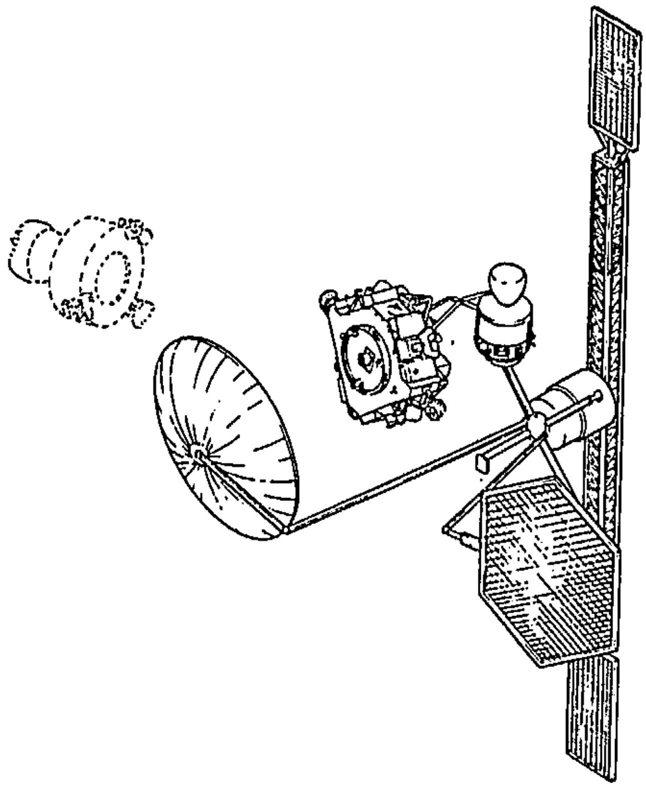

*Figure 2.2.5-5 Remote Servicing - Intelligent Servicer*

In addition, most resuppliable satellite expendables; propellants, pressurants, batteries, instrument coolant and gases, etc., will be resupplied at this time, to support satellite life extension.

Following completion of all repair and resupply operations, ground control (SSGC or a POCC) will conduct operational checkouts of all satellite systems, will retract fault isolation cables and stabilizer support mechanisms and initiate separation from the newly restored satellite.

All of these operations are conducted remotely, semi-automatically, with critical events under the control of humans at Space Station Ground Control.

### 2.2.5.1 Pre-Mission Events

To conduct the remote servicing mission at the Experimental Geostationary Platform (XGP), a number of pre-mission start activities have to be completed. The Intelligent Servicer must be prepared for transport to Space Station. Procedures for supervisory control of the Intelligent Servicer will have been developed and ground tested.

At Space Station, the Intelligent Servicer must be delivered, and operationally validated with tasks including; mating with OMV; transfer out to simulated systems in Space Station proximity; and berthing and deberthing operations.

All expendables planned for resupply at the malfunctioning remote satellite (at XGP in GEO), must be delivered to Space Station and loaded onboard the Intelligent Servicer prior to formation of the Transfer Stack.

All of the data bases within the artificial intelligence (AI) system must be updated with the latest functioning satellite design and maintenance fault isolation/restoral data and with latest expert system decision based algorithms.

### 2.2.5.2 TDM 5 - Mission Event Sequence

The detailed flow of mission activities for TDM 5 begins with preparation of the transfer stack for delivery to geostationary orbit. The mission event sequence is shown in Table 2.2.5.2-1. Again, for common sequences the reader is referenced to the appropriate table in Appendix A. The total TDM 5 mission elapsed time is estimated at approximately 50 hours. Some questions arose during development of the event sequence, that had major impacts on projection of mission operations. The first relates to the degree of proximity operations capability to be provided for OTV. It was assumed that OTV will not possess proximity operations maneuvering motors. Thus, an OMV or OMV-like vehicle will be required to: 1) maneuver the OTV away from the Space Station to enable main engine ignition with minimum contamination danger; 2) serve as a proximity operations maneuvering vehicle (with the Intelligent Servicer (IS) attached) at the XGP; and 3) maneuver the OTV back to the Space Station from its rendezvous position in relation to Space Station upon return from GEO.

Table 2.2.5.2-1

TDM 5 Mission Activity Sequence

| Event | Time | Elapsed Time |
|---|---|---|
| Form transfer stack with OMV2 OTV/OMV1/intelligent servicer (IS)(Table I) | 15 + 42 | 15 + 42 |
| OTV delivers transfer stack to desired orbit. | 6 hr | 21 + 42 |
| OMV1/IS servicer separate from OTV. | 5 min | 21 + 47 |
| OMV rendezvous/grapples experimental geostationary platform (XGP) (Table B). | 42 min | 22 + 29 |
| Configure OMV1 for IS operations | 1 min | 22 + 30 |
| • Turn off docking lights<br>• Turn off cameras 1 and 2<br>• Turn off video processor | | |
| IS attaches fault isolation/detection cable/connector to test ports of XGP | 15 min | 22 + 45 |
| Turn on scientific instruments/open all ports | 15 min | 22 + 50 |
| Fault isolation process under supervisory control of ground control | | |
| Conduct highly automated fault detection/ isolation plan with artificial intelligence (AI)/advanced manipulator system | 90 min | 24 + 20 |
| Conduct image understanding operations using: | | |
| • Advanced multiple arm manipulator: Lightweight, dexterous, 7 DOF<br>• Advanced sensors: proximity, tactile, force moment<br>• 3-D laser scanner<br>• computer vision system<br>• color stereo camera | | |
| Correlate new images/data with stored data | 15 min | 24 + 35 |
| AI system performs analysis, troubleshooting, and decision oriented comparisons | 90 min | 26 + 05 |

Table 2.2.5.2-1

TDM 5 Mission Activity Sequence

| Event | Time | Elapsed Time |
|---|---|---|
| Above 4 actions conducted simultaneously and interactively to achieve fault isolation | | |
| IS translates from one test port to another as required to complete fault isolation | | |
| Fault detection sequence concluded/ decisions/recommenced actions communicated from AI expert system to ground control using advanced data transmission system to provide fault isolation data and alternative system restoration approaches | 5 min | 26 + 10 |
| Ground control approves fault isolation decision/selects restoral approach and directs system restoration activities be initiated. | 15 min | 26 + 25 |
| System restoration activities initiated by AI expert system to include:<br>• Automated manipulator LRU removal(s)<br>• Temporary storage and retrieval if replacement LRU(s) from IS<br>• Replacement of LRU in degraded satellite instrument systems | 30 min | 26 + 55 |
| Appropriate ground control interactions with IS expedite completion of restoration activities | | |
| IS conducts satellite propellant/pressurant/ instrument gas and appropriate expendable resupply/replenishment | 2 hr | 28 + 55 |
| Ground control conducts complete operational checkout of satellite systems prior to OMV1/IS departure | 30 min | 29 + 25 |
| IS retracts fault isolation/ detection cable/prepares for transit | 15 min | 29 + 40 |
| OMV1 retracts stabilizer supporting mechanism | 14 min | 29 + 55 |
| Configure XGP for separation<br>• Turn off scientific instruments<br>• Close all ports | 5 min | 30 + 00 |

Table 2.2.5.2-1

TDM 5 Mission Activity Sequence

| Event | Time | Elapsed Time |
|---|---|---|
| OMV1/IS separate from XGP by cold gas thrust controlled by ground control | 5 min | 30 + 05 |
| Configure XGP for operations:<br>• Open all ports<br>• Turn on all scientific instruments | 5 min | 30 + 10 |
| Conduct final checkout satellite by ground control to ensure full range of operability prior to departure of IS | 30 min | 30 + 40 |
| OMV/IS rendezvous/dock with OTV (Table B) | 42 min | 31 + 22 |
| OTV transits to SS | 6 hr | 37 + 22 |
| Prepare OMV2 for flight (Table A) | 2 + 45 | 40 + 07 |
| OMV2 rendezvous/dock with OTV/OMV1/IS (Table B) | 42 min | 40 + 49 |
| RMS moves to OMV2 berthing port | 10 min | 40 + 59 |
| OMV2 cold gases transfer stack back to SS | 20 min | 41 + 19 |
| RMS latches onto OMV2/transfer stack and moves to OMV fuel depot | 10 min | 41 + 29 |
| RMS berths OMV2/transfer stack to OMV fuel depot | 5 min | 41 + 34 |
| RMS releases OMV2/transfer stack/connects defueling umbilicals to OMV1 | 5 min | 41 + 39 |
| Defuel OMV1 | 1 hr | 42 + 39 |
| RMS latches onto Is/IS released from OMV1 | 5 min | 42 + 44 |
| RMS moves to storage facility | 10 min | 42 + 54 |
| RMS stores IS/RMS returns to OMV fueling depot | 15 min | 43 + 09 |
| RMS disconnects defueling umbilicals from OMV1 | 5 min | 43 + 14 |
| RMS connects defueling umbilicals to OMV2 | 5 min | 43 + 19 |
| Defuel OMV2 | 1 hr | 44 + 19 |

Table 2.2.5.2-1

TDM 5 Mission Activity Sequence

| Event | Time | Elapsed Time |
|---|---|---|
| RMS latches onto OMV1/OMV1 released from OTV | 5 min | 44 + 24 |
| RMS moves to servicing facility | 10 min | 44 + 34 |
| Refurbish OMV1 | 3 hr | NA |
| RMS moves to OMV fueling depot | 10 min | 44 + 44 |
| RMS latches onto OTV/OTV released from OMV2 | 5 min | 44 + 49 |
| RMS moves to OTV fueling depot | 10 min | 44 + 59 |
| RMS berths OTV to fueling depot/releases OTV | 5 min | 45 + 04 |
| RMS connects defueling umbilicals to OTV | 5 min | 45 + 09 |
| Defuel OTV | 3 hr | 48 + 09 |
| RMS moves to OMV fuel depot | 10 min | 48 + 19 |
| RMS disconnects defueling umbilicals from OMV2 | 5 min | 48 + 24 |
| RMS moves OMV2 to servicing facility | 10 min | 48 + 34 |
| Refurbish OMV2 | 3 hr | NA |
| RMS moves to OTV fueling depot | 10 min | 48 + 44 |
| RMS disconnects defueling umbilicals from OTV | 5 min | 48 + 49 |
| RMS latches onto OTV/OTV released from fuel depot berthing port | 5 min | 48 + 54 |
| RMS moves OTV storage facility | 10 min | 49 + 04 |
| RMS pushes OTV into OTV storage facility/OTV berths | 10 min | 49 + 19 |
| Refurbish OTV | 3-12 hr | NA |
| Deactivate OMV control system | 1 min | 49 + 20 |
| Deactivate RMS control system | 1 min | 49 + 21 |

As shown in Table 2.2.5.2-1, this assumption will require two OMVs for conduct of the TDM. The first OMV will be positioned between OTV and IS in the transfer stack. The second is required to maneuver the Transfer Stack away from Space Station for OTV main engine(s) ignition and to maneuver the Transfer Stack back to Space Station upon return.

Another event sequence concern related to OTV refurbishment. OTV refurbishment remains highly uncertain at this point in time, as the configuration for a space-based reusable vehicle has yet to be defined. Thus, OTV refurbishment is not included in this scenario, even though OMV refurbishment is included.

TDM 5 is a complex mission comprised of many activities for which a substantial degree of uncertainty exists presently. The operations associated with both the OTV and the Intelligent Servicers are categorized as technical projections at best. There is little doubt, however, that with appropriate resource allocation, TDM 5 is a reasonable projection of servicing potential from the Space Station in the late 1990s.

### 2.2.5.3 Post-Mission Activities

Post mission activities for TDM 5 are minimal. The Intelligent Servicer will be retained at the Space Station for future planned missions, but unused replacement parts, carried to GEO in the IS, will be returned to earth.

Mission operating procedures will be reviewed to take maximum advantage of "lessons learned".

The progressive application of: 1) the concept of autonomous operations under supervisory control, and 2) the new advanced automation equipment (manipulators, sensors, computervision, three dimensional laser imaging, etc), will be reviewed and analyzed to channel the continuing evolution of servicer related automation advances.

### 2.2.5.4 Technology Development - TDM 5

The detailed definition of TDM 5 supported identification of a number of required technology developments essential to the implementation of this servicing demonstration mission. These requisite technology developments are categorized as shown in Figure 2.2.5.4-1. The enabling technologies necessary to accommodate future evolutionary changes in space automation are closely tied to advances in computers and peripheral equipment. Advances in a number of related technology areas such as manipulators, sensors, control modes and simulators will have important effects.

Though all are important, the key technology development areas are: artificial intelligence, including path planners, expert systems, natural language interfaces and advanced decisional algorithms; information processing with mass memory and high speed signal processing advancements; and sensory perception, including vision, and tactile touch and proximity systems.

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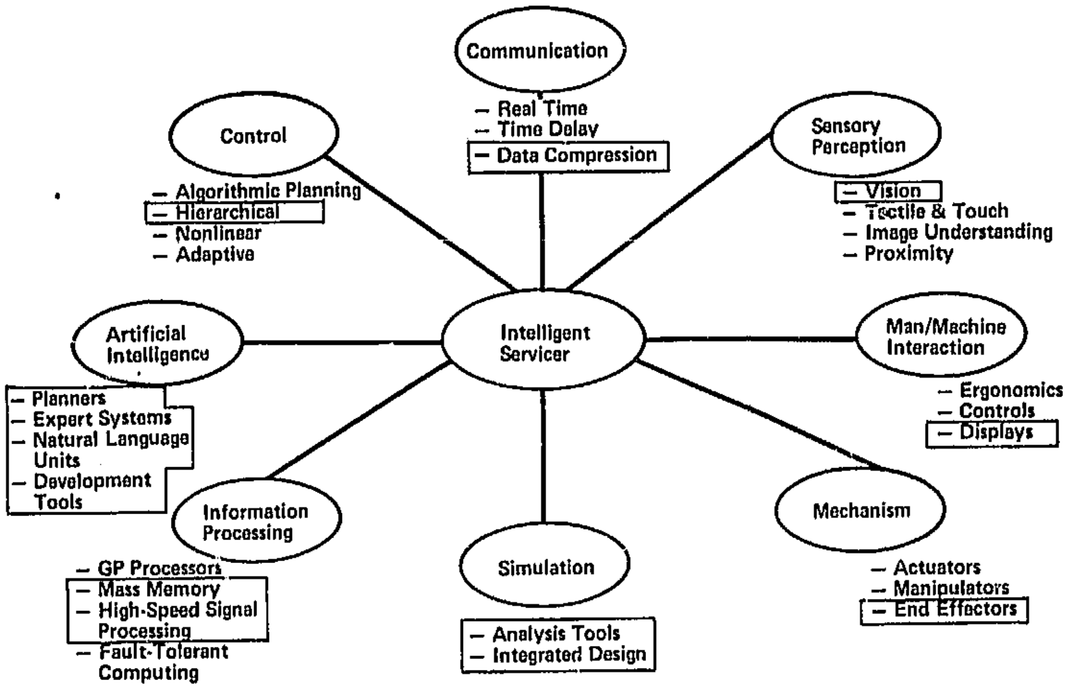


*Figure 2.2.5.4-1 Technology Development for Intelligent Servicer*

The Intelligent Servicer (IS) system level configuration envisioned in the 1997-2000 time frame would use state-of-the-art technology of 1991. The outward appearance would retain the same features of an initial IOC servicer with the majority of changes taking place in replaceable mechanisms, advanced sensors, computer software/hardware, and specific control station elements.

Technology identified, developed, and integrated at this time must retain evolvability aspects. It is increasingly apparent that sequential technology development will constantly be evolving, defining new and challenging requirements into 1997, and beyond the year 2000. Estimated evolutionary capabilities projected within the related technologies are summarized below.

Manipulators and end effectors should be more specialized. Specific requirements of these interchangeable mechanisms would include better performance to weight ratios, faster responses, greater accuracy, and more dexterity. Significant advances are expected in the sensor field, including extensive improvements in touch and proximity sensors, which when combined with manipulators dexterity and image understanding (vision) enhancements, will enable complex non-programmed servicing operations to be conducted on critical satellites with highly increased safety. The vision system will incorporate the latest stereo camera techniques along with full color capability. An alternate capability would be provided by an add-on machine processing and understanding subsystem that will allow computers to monitor many facets of the work environment.

The volatility and rapid evolution of computer-related equipment and machine intelligence technology make any forecasts in the area highly uncertain. Projecting the actual automation characteristics, available to the Intelligent Servicer at any point in time, requires an in-depth understanding of the potential synergistic effects available though various technology developments.

### 2.2.5.5 STS Flight Experiments - TDM 5

Validation of space automation technology development advances, leading to the development of an Intelligent Servicer, offers a vast array of potential STS flight experiments. The equipment designed to perform image understanding tasks at a remote site will require onorbit proof-of-concept testing. Advanced manipulators, sensor systems, vision systems will have to be integrated with artificial intelligence "expert systems" and validated in a zero-gravity environment. Advanced docking systems, either teleoperated or autonomous, will require STS test flights.

Following development of the Intelligent Servicer, a series of well construed, integrated STS tests will be required for equipment and operations validation. STS flight experiments demonstrating the capability to mate the OMV and Intelligent Servicer will be needed. Experiments testing the capability to dock the OMV/IS to a high fidelity "inoperative satellite" in proximity to STS, and perform teleoperated fault isolation and system recovery operations will also be required.

2.2.5.6 Technology Development/TDM Implementation - TDM 5

A Technology Development/TDM Implementation Plan and Schedule, shown in Figure 2.2.5.6-1. This plan provides a roadmap for the technology development required to evolve the state of automation technology to the point where an Intelligent Servicer could be designed and developed. It also outlines the TDM activity timeline recommended to enable implementation of this advanced servicing mission in the late 1990s.

As shown, manipulator advancements, computer vision, sensor advancements and artificial intelligence developments will evolve in parallel paths and at varying rates. Early in 1992, the development of the Intelligent Servicer will be initiated, leading to ground, STS and Space Station test and validation. STS flight experiments are indicated with specified validation objectives.

TDM implementation activities will commence also in 1992, necessitating ongoing coordination with both OTV and Intelligent Servicer programs. Following requisite precursor validation activities for OTV and Intelligent Servicer, both on STS and the Space Station, TDM 5 could be conducted in 1997.

## 2.3 Phase 2 TDM Validation

As a summary of Phase 2 TDM Detailed Definition, the study team developed a validation matrix to assess the degree to which implementation of the five selected and approved servicing scenarios would demonstrate total servicing requirements. This validation is illustrated beginning in Figure 2.3-1. During Phase 1 of the study this servicing task and location matrix was generated and presented. The matrix was presented also to Space Station Concept Development Groups, including the Satellite Servicing and OMV/OTV working groups. It has appeared to encompass a generally accepted broad perspective of servicing tasks expected to be conducted at or from the Space Station.

The TDM validation matrix displayed in Figure 2.3-2, shows that for those activities related to satellite servicing tasks; Space Station assembly, orbit transfer, resupply and maintenance, and not including servicing of the station itself, (the area enclosed in the heavy border), the five TDMs cover 13 of the possible 25 servicing scenarios. Thus, the five TDMs demonstrate over 50% of potential servicing scenarios to future users.

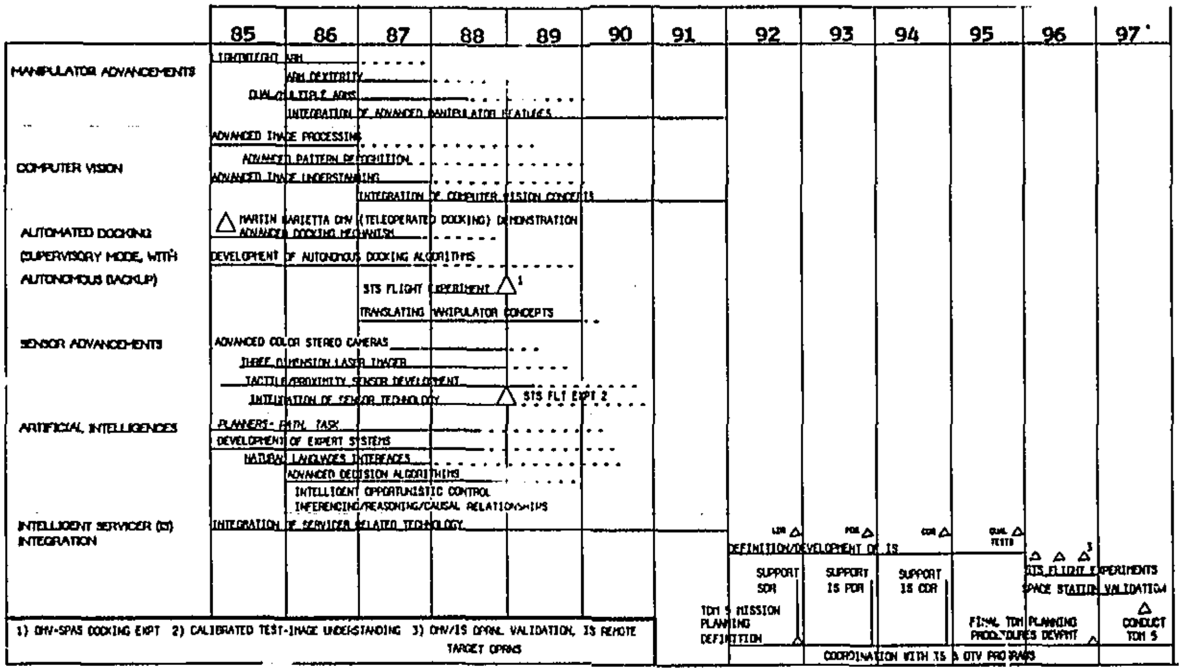


Figure 2.2.5.6-1 TDM 5 - Technology Development/TDM Implementation

| Servicing Tasks | Servicing Sub-Tasks | Servicing Locations: Space Station | S/C Berthed at S/S | S/C in LEO: S/S Plat. | S/C in LEO: User S/C | S/C in GEO |
|---|---|---|---|---|---|---|
| Large Structures Assembly/ Modification | Space Station Assembly/Modification | ✓ | | ✓ | | |
| | Large S/C Assembly | ✓ | ✓ | | | |
| Orbit Transfer | Delivery | | | ✓ | ✓ | ✓ |
| | Retrieval | | | ✓ | ✓ | ✓ |
| Resupply | Fluids - Earth Storable Mono, Bi-Prop | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Fluids - Cryogen | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Mtrls - Logistics Raw Materials | ✓ | ✓ | ✓ | ✓ | ✓ |
| Maintenance -Preventive -Corrective | Module Replacement | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Refurbishment | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Decontamination | ✓ | ✓ | ✓ | ✓ | ✓ |

*Figure 2.3-1 OMV/OTV/Satellite Servicing - A Broad Perspective*

| Servicing Tasks | Servicing Sub-Tasks | Servicing Locations: Space Station | S/C Berthed at S/S | S/C in LEO: S/S Plat/ User S/C | S/C in LEO |
|---|---|---|---|---|---|
| Assembly | S/S System Assembly/ Modification | X | | | |
| | Large S/C Assembly | X | | | |
| Orbit Transfer | Delivery | | X | X | X |
| | Retrieval | | | X | X |
| Resupply | Fluids - Earth Storable - Mono, Bi-Prop | X | X | X | X |
| | Fluids - Cryogen | X | X | X | X |
| | Mtrls - Logistics - Raw Materials | X | X | X | X |
| Maintenance | Module Replacement | X | X | X | X |
| | Refurbishment | X | X | X | X |
| | Decontamination | X | X | X | X |

*Figure 2.3-2 Selected TDM's Validate Servicing Requirements*

# 3.0 DESIGN REQUIREMENTS ANALYSIS

## 3.1 Objectives and Approach

The principal objective of the Design Requirements Analysis task for the Phase 2 study was to expand and refine the existing knowledge base of Space Station satellite servicing accommodation needs; i.e., service hangars, storage facilities, reusable transfer vehicles, etc. A secondary objective was to establish a set of spacecraft design criteria to serve as guidelines for those planning to configure their satellites for servicing at the Space Station. An additional objective was to define servicing interface requirements and accommodations.

The design requirement analysis approach used by Martin Marieta is shown in Figure 3.1-1. As each of the TDMs were defined at expanding levels of detail, functional and operational analyses produced specific servicing requirements. These requirements were entered into a master requirements data base. There were many duplicative requirements, particularly related to EVA, OMV and MMU, as use of these equipments and operations were common in many of the TDMs. The requirements data base was purged of duplicates to eliminate redundancy.

Space Station accommodation needs were then developed from the derived servicing requirements. In addition, some selective design concepts were provided to illustrate potential approaches for satisfying the servicing needs. Finally spacecraft servicing design criteria were outlined, and a Space Station servicing interface analysis was conducted to provide added insight to the total complement of satellite servicing requirements and accommodation needs.

## 3.2 Servicing Requirements/Accommodation Needs

With the completion of TDM detailed definition, the associated derived requirements data base was readied for refinement and definition of accommodation needs. This data base was thoroughly reviewed for redundancy. Next, the requirements were grouped into logical sets, to support definition of major categories of Space Station servicing elements and support equipment. These servicing elements, such as servicing hangar(s)/facilities, servicing storage needs, and reusable transport vehicles, had been identified in the Phase 1 study and were reverified as major servicing needs during Phase 2 analyses. This regrouping of servicing requirements is shown in Figure 3.2-1. The total set of requirements were classified as relating to; servicing facility, berthing/storage, fluid storage/transfer, satellite transport, and assembly.

The first category, those requirements identified as relating to a servicing hangar/facility include: requirements to berth and stabilize a satellite for servicing (to support maintenance, repair and retrofit (MR&R) activities on satellites); and to provide satellite checkout, mate and demate activities (to support servicing done in conjunction with satellite delivery and retrieval operations). These are representation top level requirements.

A second example from Figure 3.2-1 is fluid storage and transfer.

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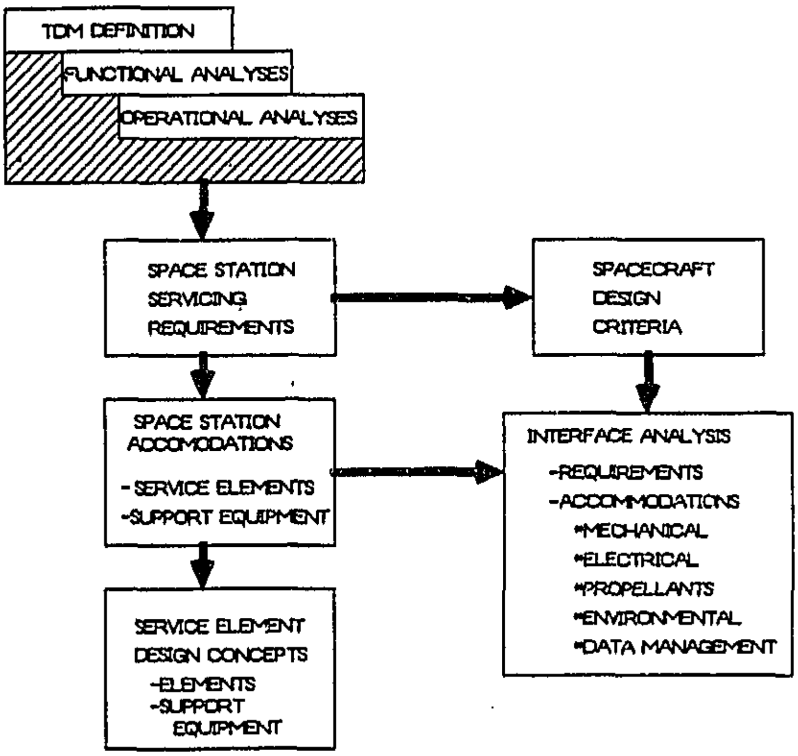


*Figure 3.1-1 Design Requirements Analysis Process*

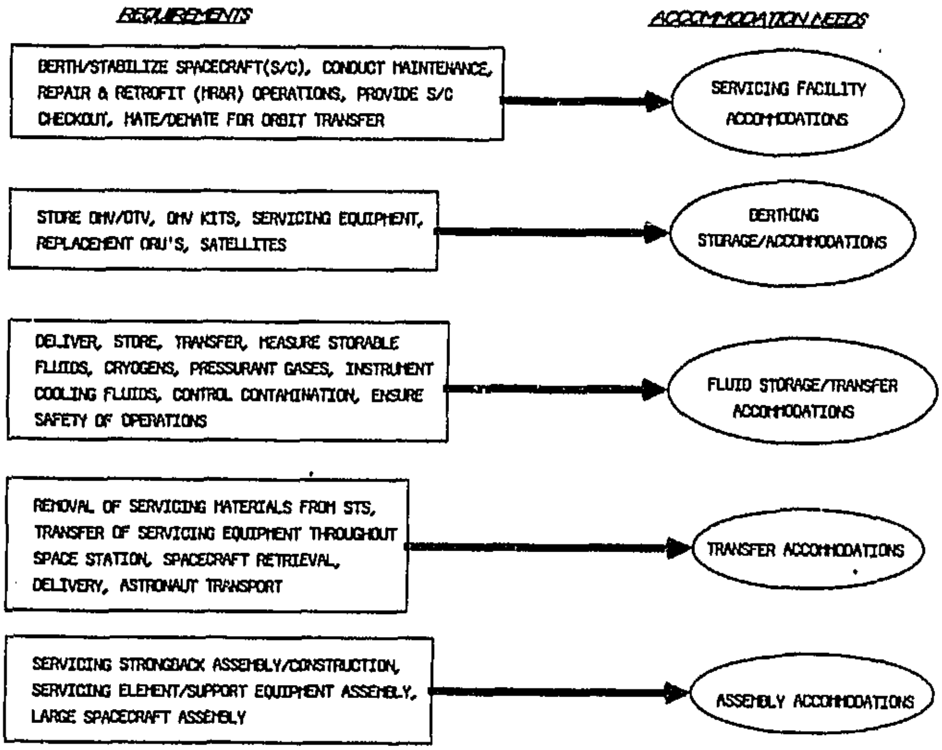


*Figure 3.2-1 Space Station Servicing Requirements/Accommodations*

Related fluid servicing requirements such as: deliver fluids, store, supply/resupply and measure both storable fluids and cryogenics; control contamination relative to fluid transfer, and ensure safety of operations, were grouped together to support definition of the Space Station accommodation needs for storage and transfer of fluids.

### 3.2.1 Servicing Accommodation Needs

The next phase of Design Requirements Analysis incorporated the translation of requirements into specific Space Station accommodation needs, i.e., the elements and support equipment needed to facilitate servicing. The first category of accommodation needs, those related to the servicing facility is shown in Figure 3.2.1-1. An expanded grouping of requirements and specific related accommodation needs for a servicing hangar or servicing "facility" are displayed. These requirements are top level, but encompass a broad spectrum of the types and levels of servicing requirements that must be satisfied to enable satellite servicing. For the specific purpose of this study, requirements such as: provide full access to an AXAF spacecraft for MR&R activities; enable mating of OMV and AXAF or OMV front end kits; and contamination monitoring/shielding of spacecraft elements during replacement; will demand satisfaction to enable conduct of the selected TDMs.

The suggested accommodation needs, shown at the right of Figure 3.2.1-1, are potential solution sets, designed to provide satisfaction of the identified servicing requirements. For example, a rotatable carousel berthing assembly, could be used for berthing and stabilizing satellites (and perhaps OMV). A translatable work station, equipped with manipulator foot restraints (MFR), is one approach to satisfying the need to provide full access to AXAF for MR&R activities.

One implementation of the Servicing Facility accommodation needs, shown in Figure 3.2.1-2 would ridigize the payload to be serviced on a carousel mechanism. The mechanical interface between a payload and the servicing facility forms the basis of the payload-servicing facility interface. In the implementation depicted in Figure 3.2.1-2, a boost vehicle-type interface is shown. The carousel should be designed to accommodate a range of interface rings (OMV, OTV, MMS, TOS, Centaur, etc), as this will allow a wide range of satellites to be serviced at the facility. The carousel mechanism can rotate and translate payloads allowing almost spherical access.

Mobile work stations and extendable ladders with toe holds are provided at the facility to ease astronaut positioning for servicing tasks. Tool and module storage is located where it can be easily accessed by the mobile work stations. A service facility RMS is used to capture and position payloads as well as to maneuver an astronaut where desired. Equipment racks and umbilical management and storage areas are provided for payload power and thermal support, data processing, communication control, and Servicing Facility operations control. A platform with toe holds restrains equipment rack operators. Adequate lighting, contamination monitoring, and safety equipment would also be provided at the facility. Micrometeoroid protection is afforded by the facility enclosure, with extensive access provided by STS cargo bay-like doors.

*REQUIREMENTS*

- BERTH OMV/SATELLITES
- STABILIZE FOR SERVICE OPERATIONS
- PROVIDE CONTAMINATION SHIELDING
- PROVIDE LIGHTING
- PROVIDE FULL ACCESS TO OMV/SPACECRAFT FOR M&R AND R*
- PROVIDE POWER/DATA HANDLING CHANNELS TO OMV/SPACECRAFT
- CONTAMINATION MONITORING/CONTROL/SHIELDING
- REMOVE ACCESS PANELS
- REPLACE MODULES
- REPLACE PRESSURIZED TANKS
- REMOVE/REPLACE INSULATION
- REMOVE REPLACEMENT ORU'S/PRESSURIZED TANKS FROM STORAGE
- DISPOSE OF USED ORU'S/PRESSURIZED TANKS
- SECURE ACCESS PANELS
- PROVIDE CHECKOUT CAPABILITY FOR OMV/SPACECRAFT
- ENABLE MATING OF OMV/SPACECRAFT
- PROVIDE DEBERTHING OF OMV/SPACECRAFT
- TRANSFER TO AND FROM SERVICING FACILITY

* M&R AND R- MAINTENANCE, REPAIR, & RETROFIT

*ACCOMMODATION NEEDS*

- SAFETY EQUIPMENT, LIGHTING
- BERTHING MECHANISM(S)
- PAYLOAD CRADLE/CAROUSEL MECHANISM
- SPACE STATION RMS CONTROL CONSOLE
- MATING/DEMATING MECHANISMS, ALIGNMENT
- RMS ACCESS TO FACILITY FOR RECEIPT OF OMV/SPACECRAFT
- COLLAPSABLE SHIELDING, OPENING SHELTER DOOR/SLIDING WALLS, NO SHIELDING
- THERMAL, RADIATION, MICROMETERIOD PROTECTION
- TRANSLATABLE WORK STATION(S)
- PAYLOAD SUPPORT: POWER/DATA HANDLING THERMAL
- COMMUNICATIONS
  - COMMAND/TELEMETRY VIA TDRSS TO SS GROUND CONTROL/POCC
  - CCTV AND VOICE
  - DATA DISPLAY, STORAGE, PROCESSING CONTROL
  - GPS DATA RECEPTION
- MODULE CHANGEOUT EQUIPMENT FIXTURES
- FOOT RESTRAINTS, HANDHOLDS
- CONTAMINATION MONITORING, SHIELDING
- STORAGE FOR EXPENDABLES, BATTERIES, TAPES

*Figure 3.2.1-1    Servicing Facility Accommodations*

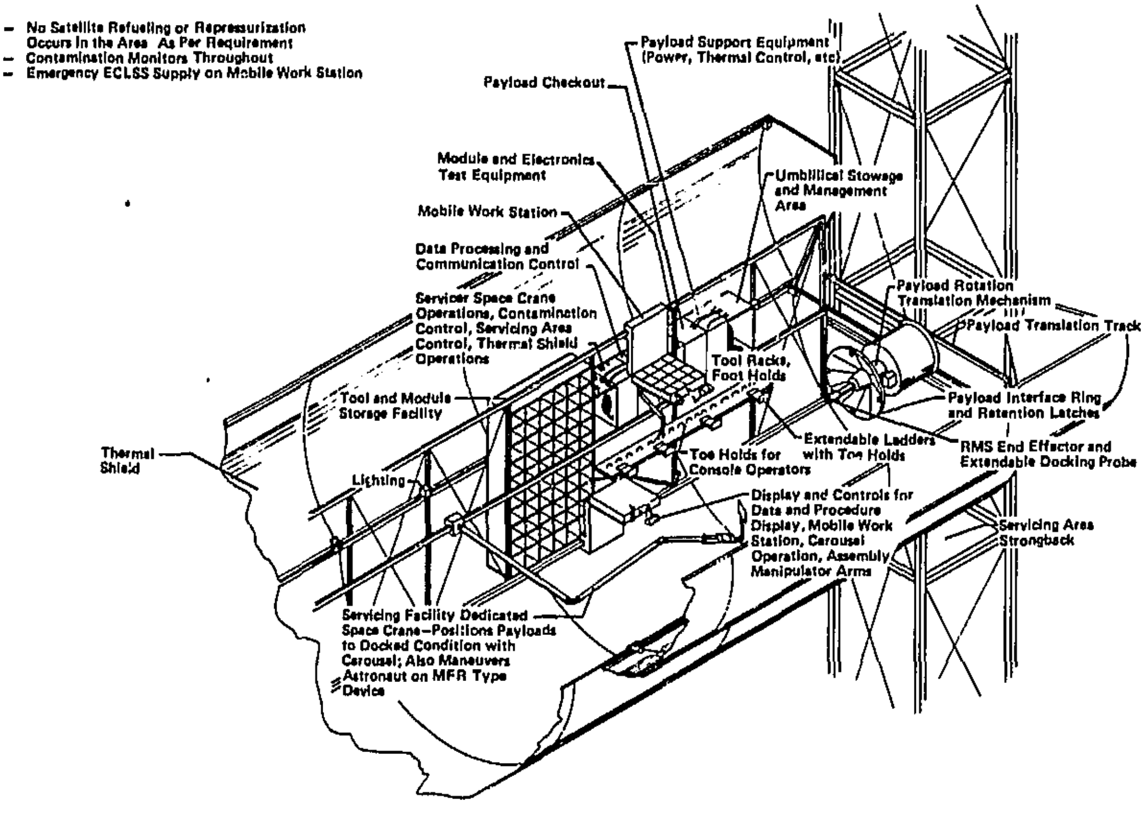


*Figure 3.2.1-2 Servicing Facility with Rotation Capability*

Another servicing facility, a Space Station servicing bay dedicated to servicing the OTV is shown in Figure 3.2.1-3. The orbiter cargo bay-like doors open to enable berthing of the OTV by a Space Crane/RMS, following a mission. Both routine and contingency turnaround operations, including aerobrake removal for ease of vehicle check-out and servicing, will be conducted here. The doors will also be opened for radial main propellant tank removal and replacement. They will remain closed for most of the refurbishment turnaround operations, however, to provide needed micrometeoroid protection.

Also shown is a conceptual dual armed manipulator system that could be attached to mobile work platforms and translated to areas and subsystems on the vehicle that lend themselves to automated servicing. As the OTV servicing and refurbishment tasks become better defined and routine, these tasks will become candidates for increased automation to enhance human productivity in the Space Station.

### 3.2.2 Storage and Berthing Accommodation Needs

The storage and berthing requirements for each TDM were reviewed and transposed into accommodation needs as shown in Table 3.2.2-1. Storage needs for five servicing categories; spacecraft, OMV related, OTV related, satellite replacement ports, and equipment/tools, were identified. Exterior berthing parts will be needed for spacecraft being stored temporarily at Space Station, prior to transfer into their operational orbits or while awaiting entry into a Space Station servicing facility.

The OMV(s) will be permanently berthed at the station, and will require shielded berthing/storage for extended Space Station operations. Storage will also be required for OMV front end kits and OMV-related ORUs.

The need to store satellite replacement parts, such as bulky ORUs, batteries, gas bottles, and even solar arrays and antennas was also identified. These storage needs will improve demands for both internal and external storage, with varying size and shielding needs.

Standard Space Station servicing tools and equipment, and satellite-unique tools will all have to be either permanently or temporarily stored at the station.

### 3.2.3 Fluid Storage and Transfer Accommodation Needs

A review of the requirements data base for all TDMs provided fluid storage and transfer requirements for operations involving OMV, OTV and satellites being serviced at the station. Fluid related servicing accommodations were derived from these requirements as shown in Table 3.2.3-1.

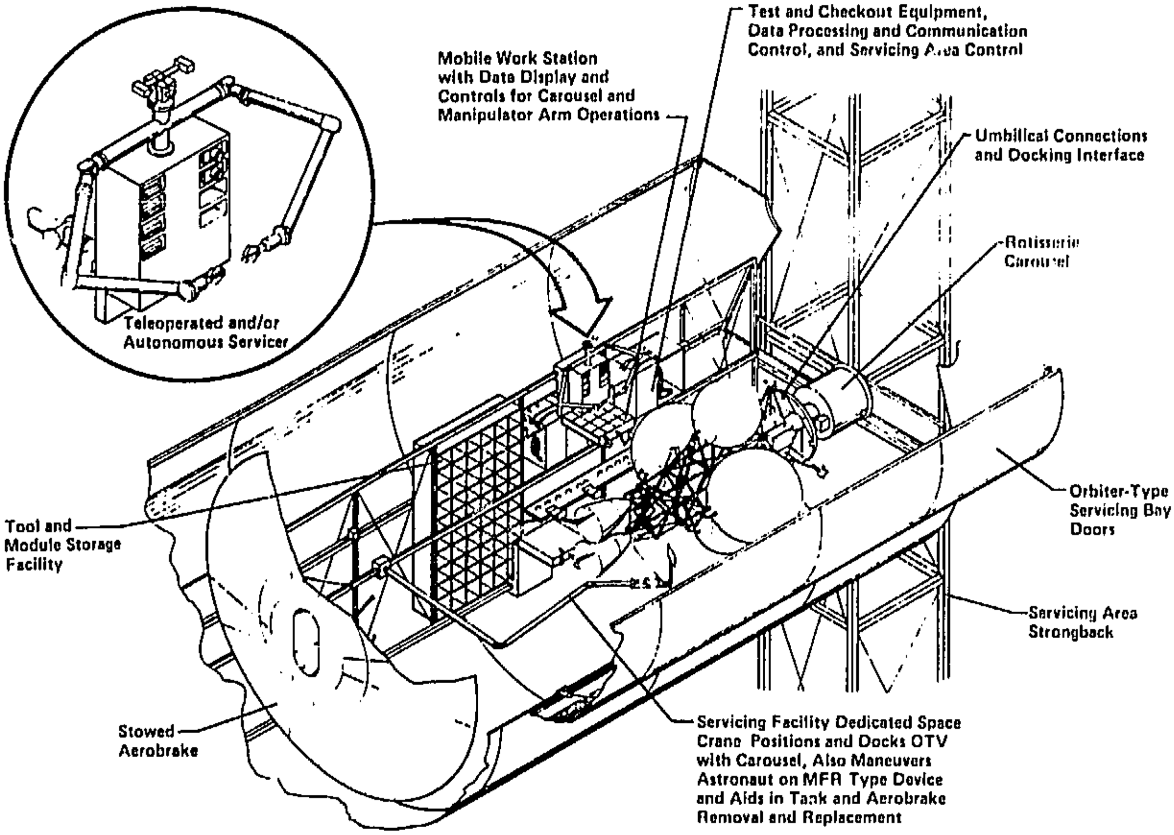


*Figure 3.2.1-3 Space Based OTV Servicing Facility*

*Table 3.2.2-1 Storage Berthing Accommodations*

| REQUIREMENTS | ACCOMMODATIONS |
|---|---|
| SPACECRAFT | |
| -TEMPORARY SATELLITE STORAGE/BERTHING FOR SATELLITE BEING SERVICED<br>- OMV STORAGE, OTV STORAGE<br>-STORAGE/BERTHING OF INTERIM SPACECRAFT ELEMENTS DURING ASSEMBLY | - EXTERIOR BERTHING PORTS<br>- STANDARD INTERFACE MECHANISMS FOR POWER, DATA THERMAL, BASING SUPPORT<br>- SHIELDED STORAGE FROM THERMAL, RADIATION, AND MICROMETERIOD THREATS |
| OMV | |
| - ORBITAL MANUEVERING VEHICLE (OMV) INITIAL OMV MISSION KITS<br>- OFFSET/SKEWD DOCKING KITS<br>- TOS/CENTAUR ADAPTER KITS<br>- ELECTRONIC RADAR KITS<br>- EXTENDED MISSION CAPABILITY MISSION KITS<br>- SERVICER/MANIPULATOR<br>- TANKER<br>- DEBRIS COLLECTION<br>- OMV ORU'S ABOUT 20, VARYING SIZES | - EXTERNAL BERTHING (NO SHIELDING REQUIRED)<br>- POWER, THERMAL PROTECTION, MONITOR SYSTEM<br>- SHIELDED STORAGE<br>- MICROMETERIOD, THERMAL, RADIATION<br>- SYSTEM MONITORING |
| OTV (NOT INCLUDED) | |
| SATELLITE REPLACEMENT PARTS | |
| - ORU'S<br>- BATTERIES<br>- FILM, TAPE<br>- SOLAR ARRAYS, ANTENNAS | - INTERNAL, EXTERNAL STORAGE AREAS REQUIRED<br>- SOME ORU'S ARE BULKY<br>- SHIELDING REQUIREMENTS VARY |
| EQUIPMENT/TOOLS | |
| - SPACE STATION SPECIFIC MAINTENANCE TOOLS, EQUIPMENT<br>- SATELLITE/SPACECRAFT UNIQUE TOOLS, EQUIPMENT | - PERMANENT UNSHIELDED STORAGE HANGER/FACILITY FOR TEMPORARY STORAGE OF MISSION UNIQUE TOOL EQUIPMENT, MFR, MESA<br>- PERMANENT SHIELDED STORAGE HANGERS/FACILITIES FOR STORAGE OF SPACE STATION UNIQUE EQUIPMENT TOOLS, MMU |

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*Table 3.2.3-1 Fluid Storage/Transfer Accommodations*

| REQUIREMENTS | ACCOMMODATIONS |
| --- | --- |
| **OMV**<br>- DELIVER BI-PROPELLANTS (MMH/NTO), PRESSURANT (HE), AND COLD GAS (N) TO SPACE STATION<br>- STORE IN FACILITY DESIGNED FOR TRANSFER<br>- TRANSFER TO OMV, MEASURE AMOUNT TRANSFERRED, RESIDUAL FLUIDS<br>- MONITOR, CONTROL CONTAMINATION<br>- ENSURE SAFETY OF OPERATIONS | - BERTHING FOR OMV AT FUEL DEPOT<br>- OMV FUEL DEPOT TO STORE/TRANSFER PROPELLANTS, PRESSURANTS AND COLD GASES<br>- AUTOMATED, ROBOTIC UMBILICAL QUICK CONNECT/DISCONNECT FOR TRANSFER OPERATIONS<br>- CONTAMINATION MONITOR, CONTROL EQUIPMENT, SHIELDS<br>- VENTING EQUIPMENT |
| **OTV**<br>- DELIVER CRYOGENS, PRESSURANTS<br>- STORE IN FACILITY DESIGNED FOR TRANSFER<br>- TRANSFER TO OTV, MEASURE AMOUNT TRANSFERRED, RESIDUAL FLUID<br>- MONITOR, CONTROL CONTAMINATION<br>- ENSURE SAFETY OF OPERATIONS | - BERTHING FOR OTV AT FUEL DEPOT<br>- CRYOGEN STORAGE/SUPPLY TANKS CAPABLE OF TRANSFER TO OTV<br>- AUTOMATED, ROBOTIC CHILLDOWN, FLUID TRANSFER, UMBILICALS, AUTOMATED INTERFACE ALIGNMENT<br>- CONTAMINATION MONITOR, SHIELDS, CLEAN UP CONTROL EQUIPMENT |
| **SATELLITE/SPACECRAFT**<br>- DELIVER STORE PROPELLANTS, PRESSURANTS, INSTRUMENT GASES<br>- TRANSFER TO VEHICLES, MEASURE AMOUNT DELIVERED, RESIDUAL FLUID<br>- MONITOR, CONTROL CONTAMINATION<br>- ENSURE SAFETY OF OPERATIONS | - SPACECRAFT BERTHING AT FLUID DEPOT<br>- SPACECRAFT PROPELLANT, PRESSURANT INSTRUMENT STORAGE/SUPPLY TANKS FOR FLUID TRANSFER, REPLACEMENT TANKS/BOTTLES<br>- FLUID TRANSFER INTERFACE MECHANISMS<br>- CONTAMINATION SHIELDING, MONITOR SYSTEM, CONTROL/CLEAN UP EQUIPMENT |

The OMV requirements for fuel and pressurant storage and the need to safely conduct fueling and defueling operations, perhaps without man-in-the-loop, dictates the need for a storable fluid depot. A requirement may exist to fully automate the process with robotic or teleoperated umbilical quick disconnects for transfer operations. OTV fueling requirements mandate similar cyrogen storage and transfer accommodation needs.

Scheduled retrieval of satellites from operational orbits and return to Space Station for resupply of expendables including fuel, pressurants and instrument cooling fluids also drives Space Station accommodation needs for fluid storage and transfer capabilities, both for transfer of fluids and replacement of fluid tank bottles.

A storable fluid depot concept is illustrated at Figure 3.2.3-1. This implementation of the satellite/spacecraft/OMV Fueling Facility accommodation needs would support a satellite or OMV on a carousel mechanism and berthing ring and would connect fuel, oxidizer, pressurant and power umbilicals to the satellite/OMV fueling port with an automated connection mechanism. A video camera would provide remote monitoring of the operation by the Space Station crew. The Space Station RMS would be used to deliver the spacecraft OMV to and from the facility, as well as to change-out expended fuel, oxidizer, and pressurant tanks. The tank support structure would also provide the tank umbilical interface, housing the required propellant transfer managing and measuring equipment. Micrometeoroid protection would be afforded by a shroud surrounding the tanks.

### 3.2.4 Servicing Transfer Accommodation Needs

General transfer requirements and derived servicing accommodation needs for servicing at or from the Space Station were categorized as: 1) local for transport of equipment or men around the Space Station, and 2) remote transport of satellite to low and high energy satellite orbits from the station. These are shown at Table 3.2.4-1.

Hardware transfer requirements are extensive and variant, supporting a variety of transport accommodation needs. A translatable, remotely operated RMS will move OMVs, servicers, and satellites from berthing ports to fueling depots to servicing hangars. A moveable work station in the servicing facility will provide full access to a rotating spacecraft berthed at a carousel mechanism.

The requirement to enable manned movement about the Space Station necessitates Manned Maneuvering Units, handholds, and tethers throughout the Space Station.

Finally, requirements to deliver and retrieve satellites to and from operational orbits and to conduct remote servicing operations - cost effectively from the Space Station - will require space based, reusable low and high energy transfer vehicles, front end servicer kits for OMV, and Space Station and ground control consoles to operate them.

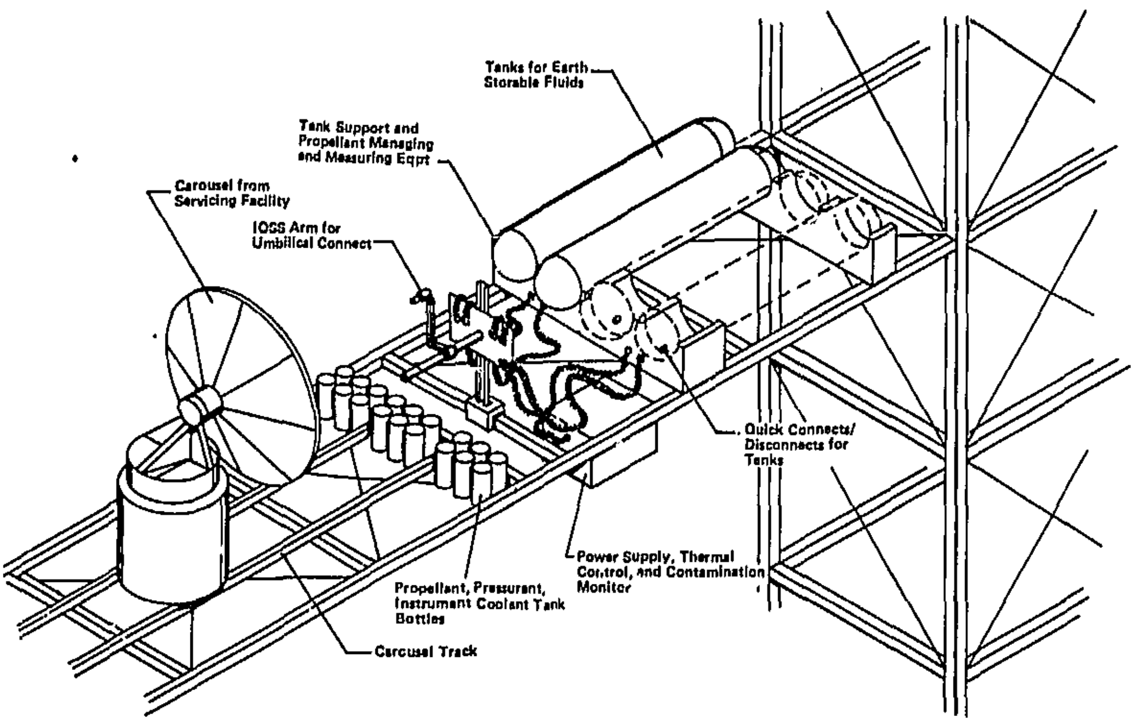


*Figure 3.2.3-1        Storable Fluid Depot*

*Table 3.2.4-1 Servicing Transfer Accommodations*

| *REQUIREMENTS* | *ACCOMMODATIONS* |
|---|---|
| **HARDWARE TRANSFER AROUND SPACE STATION** | |
| - TRANSFER OMV FROM BERTH TO FUEL DEPOT<br>- TRANSFER MATERIALS FROM STS TO SERVICING FACILITY<br>- TRANSFER SPACECRAFT ELEMENTS FROM STS TO ASSEMBLY AREA<br>- TRANSFER AXAF ORU MODULES FROM ORU CARRIER TO AXAF<br>- TRANSFER LOADED OTV FROM FUEL DEPOT TO SPACECRAFT MATING AREA<br>- REMOVE AND REPLACE MATERIALS PROCESSING MODULES AT REMOTE SPACE STATION PLATFORM | - TRANSLATABLE REMOTELY OPERATED MANIPULATOR<br>  - TRACKED, CRAWLER<br>  - SINGLE ARM, MULTI-ARM<br>- MOVEABLE WORK STATION IN SERVICE FACILITY<br>- SPACE CRANE, HEAVY LIFT, LONG REACH<br>- TELEPRESENCE WORK STATION WITH CAPABILITY SIMILAR TO EVA TASK PERFORMANCE<br>- MULTIPURPOSE (MOBILE) CONTROL CONSOLE (RMS, OMV, OTV, SPACE CRANE) |
| **EVA TRANSLATION** | |
| - ASTRONAUT TRANSPORT FROM PRESSURIZED MODULES<br>  - TO SPACE STATION ASSEMBLY AREA<br>  - TO LARGE SPACECRAFT ASSEMBLY AREA<br>  - TO ATTACHED PAYLOADS<br>  - TO SERVICING FACILITY | - ASTRONAUT HANDHOLDS, TETHERS AT SELECTED POINTS THROUGHOUT SPACE STATION/PLATFORMS/SATELLITES<br>- MMU(S)/EMU(S)- MINIMUM OF TWO |
| **TRANSPORT TO REMOTE LOCATIONS (LEO, GEO)** | |
| - DELIVER MODULE TRANSPORTER TO REMOTE MATERIALS PROCESSING PLATFORM COST EFFECTIVELY, FREQUENTLY<br>- RETRIEVE AXAF FROM DECAYED OPERATIONAL ORBIT, REBOOST<br>- DELIVER OMV/IS TO XGP SATELLITE AT GEO AND RETURN | - SPACED-BASED REUSABLE LOW ENERGY TRANSFER VEHICLE (OMV)<br>- SPACE-BASED REUSABLE HIGH ENERGY TRANSFER VEHICLE (OTV)<br>- FRONT END KITS FOR OMV TO ENABLE RETRIEVAL, MODULE REPLACEMENT, FLUID RESUPPLY, REMOTE M&R<br>- SPACE/GROUND CONTROL STATIONS FOR OMV/OTV/FRONT END KITS |

### 3.2.5 Servicing Assembly Accommodation Needs

The two assembly oriented TDMs, Space Station Assembly/Modification and Large Spacecraft Assembly provided a number of unique requirements and accommodation needs, as seen in Table 3.2.5-1.

Assembly of the service support area for the Space Station, with the delivery of a number of assembly elements on each STS flight, supported the need for a means of temporary storage of assembly elements. An STS cargo canister was recommended in conduct of this TDM, though this is not considered a firm accommodation need, only an option.

The servicing area assembly operations are extensive and will require substantial EVA time for manual assembly. For operations such as these, an advanced, automated, dual arm manipulator will improve man's productivity and is seen as an desired accommodation need.

Assembly of a complex large spacecraft such as the Large Deployable Reflector, imposes a large number of servicing requirements that will be difficult to accommodate. Many of the requirements identified in Table 3.2.5-1 have already been accommodated in previous TDMs, such as mating of spacecraft elements onorbit and positioning the spacecraft/science instrument package on a rotating berthing port. However, the attachment of mirror segments, for an adaptive mirror, to one another is viewed as an operationally challenging task. The handling, alignment, mating and latching operations are seen by program planners to be very difficult. In addition, the requirement to maintain a contamination free environment during assembly operations appears to be another servicing accommodation need that will be difficult to satisfy.

## 3.3 Spacecraft Design Criteria

A specific Martin Marietta objective in the Design Requirement Analysis process was to provide top level design criteria to serve as a reference point for planners configuring spacecraft for eventual onorbit servicing at or from the Space Station. With Space Station undefined, standard satellite/spacecraft servicing design criteria would be premature. However, from servicing operations already conducted on STS and with others planned, an outline of design criteria for eventual servicing on Space Station can be initiated. This outline is shown at Table 3.3-1. Servicing design criteria are classified according to type of user-desired activity. These include: resupply activities, such as ORU replacement, or replacement of batteries, film or other expendables; satellite maintenance repair and retrofit (MR&R); fluid transfer; and orbit transfer, either delivery or retrieval.

Spacecraft designers must first assess requirements for resupply of expendables, which provides an extension of onorbit satellite lifetimes. Developers must evaluate and compare planned satellite lifetimes with the expected satellite payload technology cycle, to ascertain whether servicing resupply activities are warranted. Then, given that the satellite will be designed for resupply, the designers should consider several factors including: standard mountings and interfaces for ORU replacement, standard alignment processes, use of standard tools, accessibility for both EVA and robotic resupply operations, and safety.

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*Table 3.2.5-1 Servicing Assembly Accommodations*

| REQUIREMENTS | ACCOMMODATIONS |
|---|---|
| **SPACE STATION ASSEMBLY**<br>- ASSEMBLE SERVICE SUPPORT AREA STRONGBACK<br>- ASSEMBLE SERVICING ASSEMBLY<br>- INSTALL CAROUSEL FOR SPACECRAFT ROTATION<br>- INSTALL TRANSLATING WORK STATION(S)<br>- INSTALL SERVICE AREA RMS/WORK STATION<br>- INSTALL FUEL DEPOT(S)<br>- INSTALL OMV BERTHING PORTS/ STORAGE HANGER | - TEMPORARY STORAGE FOR ASSEMBLY MATERIALS<br>- SPACE STATION RMS, TELEOPERATED, WITH FULL ACCESS TO SPACE STATION ELEMENTS. DUAL ARMED, WITH EVA TASK CAPABILITY<br>- MMU/EMU FOR EVA SUPPORT<br>- STS RMS, SPACE STATION RMS HAND OVER<br>- SPACE STATION RMS CONSOLE, REMOTE TELEOPERATED RMS CONSOLE |
| **LARGE SPACECRAFT ASSEMBLY**<br>- MATE SPACECRAFT/INSTRUMENT SECTIONS<br>- POSITION LDR ON ROTATING TEMPORARY BERTHING ELEMENT IN SERVICE/LARGE ASSEMBLY AREA<br>- STABILIZE LDR TO SERVICE STRONGBACK<br>- ATTACH LDR MIRROR SEGMENT CANNISTER TO STRONGBACK<br>- ATTACH MIRROR SEGMENTS TO LDR INSTRUMENT SEGMENT<br>- ATTACH SECONDARY MIRROR ASSEMBLY TO LDR ASSEMBLY<br>- APPLY SUNSHADE ELEMENTS TO LDR ASSEMBLY<br>- CHECKOUT ASSEMBLED LDR | - TEMPORARY STORAGE FOR ASSEMBLY ELEMENTS, MIRROR SEGMENTS, SUNSHADE ELEMENTS<br>- ROTATING BERTHING ELEMENT ON STRONGBACK<br>- STABILIZER BARS FOR LDR ON STRONGBACK<br>- TRANSLATABLE REMOTELY OPERATED SPACE STATION RMS, DUAL ARMED, HIGHLY AUTOMATED TELEPRESENCE WORK STATION FOR IMPROVED PRODUCTIVITY<br>- CONTAMINATION CONTROL, SHIELDING FOR LDR MIRROR SEGMENTS |

*Table 3.3-1 Spacecraft Design Criteria for Space Station Servicing*

- ***MODULAR ORBITAL REPLACEMENT UNIT (ORU) REPLACEMENT/BATTERIES/EXPENDABLES***
  - DESIGN FOR OPTIMUM ORU REPLACEMENT
    - SPACECRAFT MODULES, INSTRUMENTS
    - EXPECTED LIFETIMES, TECHNOLOGY UPGRADE CYCLE
  - STANDARD MOUNTING, INTERFACE FITTINGS, FASTENERS
  - STANDARD COURSE/FINE ALIGNMENT TECHNIQUES: PIN, SLOT, KEYS
  - PROVIDE ACCESSIBILITY: EVA, ROBOTIC OPERATIONS
  - DESIGN FOR MAXIMUM USE OF MULTI-PURPOSE TOOLS, MINIMIZE UNIQUE TOOLS
  - SAFETY: MINIMUM ASTRONAUT INTERFACE WITH STORED ENERGY, PYROTECHNIC DEVICES
  - DESIGN IN MODULARITY FOR FLEXIBLITY, GROWTH
  - PROVIDE HANDHOLDS NEAR ORU CENTER OF GRAVITY
  - MAINTAIN CONFIGURATION CONTROL

- ***SATELLITE REPAIR***
  - CONSIDER EVA/AUTOMATION ROBOTICS TRADES
    - EVA CAPABILITY NOW PROVEN
    - EVA OPERATIONS DIFFICULT, INEFFICIENT
    - AUTOMATED SYSTEMS, ROBOTICS EXPENSIVE
  - DESIGN SUBSYSTEMS FOR AUTOMATIC FAULT ISOLATION, DETECTION, RECOVERY PROCESSES
  - PROVIDE RETRACTABLE APPENDAGES
    - REDUCE CLEARANCE ENVELOPE PROBLEMS
    - PRECLUDE UNNECESSARY LOSS OF FUNCTIONING HARDWARE
  - PROVIDE HANDHOLDS, TETHER ATTACH POINTS, AND FOOT RESTRAINT SOCKETS
  - STANDARD COLOR CODES, MARKINGS, LABELS FOR EASE IN IDENTIFICATION

- ***ONORBIT FLUID TRANSFER***
  - DESIGN FOR EVA, REMOTE/AUTOMATED FLUID TRANSFER
  - PROVISION FOR HOLDING: STS TRUNNION FITTINGS, CARCUSEL MATING
  - ACCESSIBILITY FOR STANDARD UMBILICAL CONNECT: EVA, ROBOTIC
    - POWER - VENTING - CRYOGENS - COOLANTS
    - DATA - PRESSURANTS - EARTH STORABLE
    - COMBINATIONS
  - PROVIDE CONTAMINATION SHIELDING, CONTAMINATION CONTROL MEASURES
    - COMPATIBLE WITH DECONTAMINATION EQUIPMENT

- ***ORBIT TRANSFER: DELIVERY, RETRIEVAL***
  - CONFIGURE SPACECRAFT FOR MATING WITH OMV/OTV
  - COMPATIBLE WITH MANUAL/AUTOMATED ALIGNMENT PROCESSES, MATING LOADS
  - COMPATIBLE WITH, ACCESSIBLE TO POWER, DATA UMBILICALS/INTERFACES FOR OPERATIONAL CHECKOUT AT SPACE STATION
  - PROVISION FOR RETRIEVAL
    - SPACECRAFT INERTING
    - CONTAMINATION SHIELDING, DUST COVERS
    - RETRACTABLE APPENDAGES

For designers planning to accommodate satellite repair activities, a first consideration relates to how the repair operation can most effectively be accomplished, either by man (EVA) or machine (robotically or teleoperated). EVA capability has been demonstrated, but has been shown to be difficult and inefficient, in the zero-gravity environment. On the other hand autonomous systems, though expensive to develop, can pay off over time with frequently used, multi-purpose equipment. In discussions with automation experts, it has been recommended that subsystems be designed for automatic fault isolation, detection and restoral. Solar Maximum repair experience and recovery operations for the Westar and Palapa communications satellite retrieval mission, highlight the benefits of providing redeployable, retractable appendages where possible to reduce clearance envelope problems and to prevent loss of operating subsystems during repair.

Servicing design criteria considerations are also shown for planners considering onorbit fluid transfer and either delivery or retrieval operations with OMV or OTV, as shown in Table 3.3-1.

## 3.4 Space Station Servicing Interface Requirements

### 3.4.1 Interface Analysis Process

The definition of interface requirements is an important segment of Design Requirements Analysis for satellite servicing on the early Space Station. Interface requirements are the characteristics required of a design to enable effective interfaces with its operating and natural environments. For the study, the natural environment was low earth orbit, and the operating environment was defined by the selected servicing scenarios, the five TDMs.

Also, an assumption was made about the functional elements of the satellite servicing area. It was assumed these functional areas would include a service hangar (facility) for satellite maintenance, an OMV fuel depot for refueling earth storable propellants, an OTV fuel depot for refueling cryogenic propellants, an OMV berthing/storage site, an OTV storage hangar, a spacecraft temporary storage site, an MPP module storage facility, and an LDR assembly/berthing site.

The interface requirements process used with this study is shown in Figure 3.4.1-1. The process flow was initiated with a functional analysis of each TDM, with the functions delineated at the lowest or most "primitive" level. Then all functions specifically requiring an interface with the operational or natural environment were identified, and these are called functional interface requirements.

After the functional interface requirements were defined for each TDM, a single "unique" set of interfaces was defined for the Space Station servicing area, with redundant interfaces deleted.

A third step in the identification of interface requirements was to convert the functional interface requirements into physical and operational interface requirements according to type, using accepted categorizations and combining common identified interface requirements. Categorization allows the requirements to be allocated later to the proper subsystem. The categorizations used in this study were: structural/mechanical, electrical (including data handling and power), environmental, fluids, crew, and communications.

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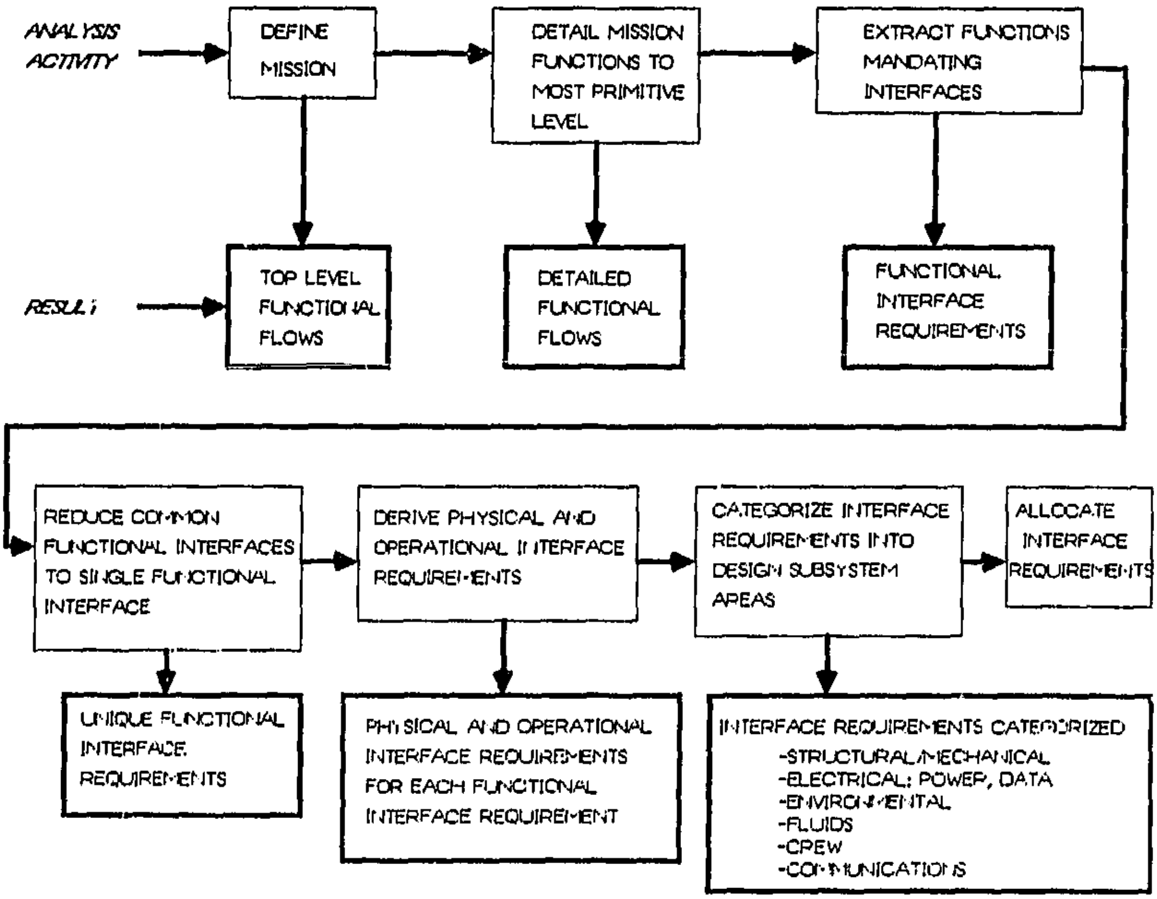


*Figure 3.4.1-1 Interface Analysis Process*

### 3.4.2 Structural/Mechanical Interface Requirements

The structural/mechanical interfaces required for servicing involve mostly: RMS end effectors to grapple satellites; berthing structures to rigidize spacecraft; umbilical connection mechanisms; and various support fixtures, storage containers and equipment in the service hangar.

The Space Station RMS must have an end effector capable of grappling the OMV, LDR, OTV, and MPP module transporter, among others. This set of requirements argues strongly for standard grappling fixtures.

Another set of structural interface requirements includes umbilical connection devices and disconnection actuation mechanisms for electrical and fueling umbilicals for OMV and OTV, at berthing/storage facilities and fueling depots.

Berthing structures and latches, with automatic latch actuation and release mechanisms will be required to form stable structural interfaces between:

- OMV and OMV fuel depot
- OMV and service hangar
- OMV and OMV storage site
- AXAF and a temporary berthing site
- LDR and a temporary berthing site
- AXAF and servicing hangar
- OTV and OTV storage site
- OTV and OTV fuel depot
- OTV payload and service hangar
- OTV service hangar

Miscellaneous structural interface requirements include; support structure for specialized satellite servicing equipment (such as ORU carrier), fuel restraints and tether attachments throughout the servicing facility, flow meters and mass guages of fuel depot tanks, OTV aerobrake handling fixture and storage site, and storage fixture and OTV engine(s).

### 3.4.3 Electrical Interface Requirements

This interface category includes data handling and service power. A data link interface from the Space Station Communication System Control Processor (CSCP), through a service/power umbilical in the service hangar, will be required to link with; the AXAF CSCP, the LDR CSCP, and the MPP CSCP. Another data interface requirement is the data link from Space Station CSCP to the OMV CSCP at the OMV storage site. Similar interface requirements exist for OTV and for LDR at the LDR assembly site.

A number of servicing power interface requirements were identified. All of the servicing support elements and satellites being serviced at Space Station will require power from station resources. Electrical umbilical interfaces will be required for; the OMV at the OMV storage/berthing site, the OTV at the OTV storage site, the OMV at a service facility and at a storable fluid depot, the OTV at a service facility and at a

cryogenic fluid depot, the AXAF at the service hangar, and LDR at its assembly site.

### 3.4.4 Environmental Interface Requirements

Environmental interface requirements were identified in three specific categories; lighting, contamination and shielding.

The primary lighting requirement supports the use of the close circuit television system (CCTV) throughout the servicing area. Adequate lighting for video representation of transfers of vehicles, using RMS, from service element to service element is essential to servicing operations. Proper lighting levels are required within the servicing hangar(s) for EVA operations and for video monitoring, at OMV and OTV storage sites, at storable and cryogenic fuel depots, at external berthing sites, and the LDR assembly site.

Contamination monitor interfaces are required at OMV and OTV fuel depots for warning and at strategic points including the service hangar for fuel and instrument cooling gas spillage.

A third environmental interface area relates to shielding requirements. A specific definition of shielding requirements is beyond the scope of this study; however, potential interfaces for: solar thermal; solar radiation; and electron, proton, and cosmic ray radiation shielding have been identified. Space Station planners must consider the need for appropriate shielding and derivative interfaces for the OMV and OTV at respective storage sites on the Space Station. Replacement modules, including the large material processing resupply modules and the large variety of AXAF modules must be temporarily stored, with varying shielding requirements. Also, satellites under repair in the service hangar will impose varying shielding requirements and associated structural and electrical interface requirements.

### 3.4.5 Fluid Interface Requirements

Fluid interfaces are difficult to define due to the uncertainty about how fluids will be stored and transferred to OMV, OTV and serviced satellites. However, fluid transfer interfaces between Space Station and OMV will be required to enable transfer of storable fuels, pressurants and proximity operations propellants, such as nitrogen cold gas. In addition, Space Station must provide fluid interfaces for transfer of cryogenic fluids and pressurants to OTV. Finally, with AXAF as an example, servicing of satellite replacement fluids will impose a potentially wide range of fluid interface requirements on the station.

### 3.4.6 Crew Interface Requirements

Crew interfaces are primarily operations interfaces, though they will impose additional physical/functional servicing interfaces on the Space Station. The crew will monitor all servicing support operations. They will monitor contamination sensors at OMV and OTV fuel depots. Personnel will operate the RMS to: transfer satellites between servicing elements; transfer equipment throughout the service hangar; move video cameras about during external visual inspection of OMV, OTV

and satellites; berth satellites and equipment at berthing sites; mate and demate, and capture and deploy satellites within the servicing area; and handle large objects including LDR, MPP modules and OTV engines.

Crewmembers will monitor RMS performance limits and ensure appropriate clearances during transfers, berthing, mating, capture, loading and unloading. Servicing operators will also monitor video during all servicing operations. They will verify that the SS CSCP is transparent to communication from ground control stations to the; OMV, OTV, AXAF, LDR, MPP and all satellites in service, and reconfigure when required.

The crew interfaces in servicing operations will be continuous and this category of requirements is the single most flexible of all requirements, both demanding change and encouraging change for operational enhancement.

### 3.4.7 Communications Interface Requirements

Communication interface requirements were identified in three areas; video, radio frequency (RF) communication links, and audio links.

CCTV video camera interfaces will be required on all strategic servicing area vantage points to cover transfers between servicing elements. Video interfaces are also required at appropriate vantage points within the service hangar, at OMV and OTV storage sites and OMV and OTV refueling depots.

RF communication link interfaces are required between the Space Station CSCP and CSCPs on OMV, OTV, AXAF, LDR, MPP and other satellites being serviced.

Finally, an audio link requirement exists between the IVA crew and any EVA crew.

## 4.0 TECHNOLOGY AND FLIGHT EXPERIMENT PLAN

### 4.1 Introduction

The objective of this Phase 2 study task was to develop a plan that would incorporate both: 1) the basic technology development required to enable Space Station servicing, and 2) the STS and Space Station flight experiments required to validate this servicing related technology. The result produced was an integrated, time-phased plan for technology development and flight validation that supports implementation of the selected TDMs. The approach used was; to collect all precursor technology activities identified in definition of the five TDMs, to collect and classify servicing technology requirements, to outline STS and Space Station onorbit validation flights/tests, and finally, to produce the plan.

### 4.2 TDM Precursor Activities

During Phase 1 and continuing into Phase 2 of the Satellite Servicing study, the importance of identifying precursor activities became increasingly clear. Precursor activities include; basic technology development required to support servicing; and definition, development and onorbit validation of Space Station servicing elements and servicing support equipment. All precursor activities must be identified, prioritized, planned and conducted along timelines that will enable conduct of TDMs designed to demonstrate specific servicing capabilities at the Space Station. Precursor activities for the five TDMs were collected and are shown in summary form on Figure 4.2-1.

For TDM1, the key precursors related to OMV. Basic technology requirements included all of the onorbit fluid transfer issues, including storage, transfer, guaging, venting and others to be outlined subsequently. A major TDM1 Space Station servicing element is definition and development of a space-based, reusable OMV. Unique precursors for TDM2 include development of the AXAF ORU carrier, and validation of a multitude of satellite repair and replenishment activities. The major precursor in TDM3 is installation and validation of the principal satellite servicing elements on Space station. TDM4 servicing precursors include definition and development of large scale adaptive mirrors, configured for assembly onorbit. In addition, servicing assembly methods and procedures, unknown today, will have to be developed and validated. TDM5 introduces a wide range of basic space automation technology development activities, and requires integration of these into a highly advanced satellite servicing support element, the Intelligent Servicer.

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**TDM 1** - MATERIALS PROCESSOR RESUPPLY

- VALIDATION OF SPACE BASED, REUSABLE OMV
- FLUID TRANSFER MANAGEMENT TECHNOLOGY
- OMV FUEL DEPOT
- TELEOPERATED/AUTONOMOUS DOCKING
- TELEOPERATED MODULE REPLACEMENT
- INTELLIGENT FRONT END FOR OMV
- TRANLATABLE MANIPULATOR FOR OMV/MODULE TRANSPORTER
- MATERIALS PROCESSING MATURITY

**TDM 2** - AXAF RETRIEVAL/REPAIR

- OMV VALIDATION
- FLUID TRANSFER MANAGEMENT
- OMV FUEL DEPOT
- SPACE STATION SERVICING SUPPORT AREA VALIDATION
- AXAF SUPPORT EQUIPMENT-ORU CARRIER
- SERVICING CAPABILITIES:ORU'S, MIRROR ASSEMBLY, SOLAR PANEL ALIGNMENT/REPLACEMENT
- EVA ENHANCEMENTS-IMPROVED SUIT, HEAD'S UP DISPLAYS
- SPACECRAFT FLUID DEPOT

**TDM 3** - SPACE STATION ASSEMBLY/MODIFICATION

- DUAL ARMED, TRANSLATING MANIPULATOR, OR SPACE CRANE
- STRUCTURAL CONCEPTS, STRONGBACK ASSEMBLY, DEPLOYABLE STRUCTURES
- STORABLE FLUID/FUEL DEPOT(S)-OMV, SATELLITES
- TRANSLATABLE WORK STATION IN SERVICE FACILITY
- VALIDATE STORAGE FACILITIES-SATELLITES, OMV, ORUS, MMU EQUIPMENT, TOOLS
- LIGHT WEIGHT SHIELDING MATERIALS, ASSEMBLY PROCESS
- LIGHTWEIGHT CARGO CANNISTERS

**TDM 4** - LARGE SPACECRAFT ASSEMBLY

- ON-ORBIT ASSEMBLY OF ADAPTIVE OPTICAL SYSTEM
- TRANSLATABLE, DUAL ARMED MANIPULATOR
- TRANLATABLE, WORK PLATFORM/CONTROL STATION
- LIGHTWEIGHT CARGO CANNISTERS
- VALIDATION OF LARGE ASSEMBLY OPERATIONS IN UNSHIELDED MODE
- CONTAMINATION P ROTECTION OF MIRROR SEGMENTS DURING ASSEMBLY

**TDM 5** - INTELLIGENT SERVICER

- MANIPULATOR ADVANCES
- COMPUTER VISION
- AUTOMATED/AUTONOMOUS DOCKING
- SENSOR ADVANCEMENTS
- ARTIFICIAL INTELIGENCE
- INTELLIGENT SERVICER SYSTEM
- OTV VALIDATION
- CRYOGENIC FLUID MANAGEMENT TECHNOLOGY

*Figure 4.2-1 TDM Precursor Activities*

## 4.3 Technology Development Requirements

During the TDM Detailed Definition phase of the study, a "technology development" data base was established, similar to the servicing requirements data base. This data base was developed through analyses of TDM precursor activities. These analyses supported identification of technology development requirements. Following completion of TDM definition, the technology development data base was inspected to ensure completeness and to eliminate redundant entries. The technology development file was then subdivided to group requirements into seven technology development areas.

These categories are presented in Figure 4.3-1, and include: fluid transfer management; space-based, reusable low energy upper stage (OMV); space-based, reusable high energy upper stage (OTV); maintenance, repair and retrofit operations; remote servicing; large object handling and translation; and servicing automation.

These technology development requirements were identified in the TDM Detailed Definition task and have been described throughout Volume II, Section 2.0 of the study report. They are summarized in the structured technology development categories as shown in Table 4.3-1.

### 4.3.1 Fluid Transfer Management

Onorbit fluid transfer management is recognized as one of the most important technology development requirements presently associated with satellite servicing. The capability to store fluids, both storable and cryogenic liquids, and transfer them to reusable OMV and OTV transfer craft, and to satellites requiring resupply of fuels, pressurants and instrument gases will be essential for servicing at Space Station. Some of the basic technology issues related to fluid transfer management are: establishment of initial conditions in receiver tanks, accuracy of measurement, control of thermal and pressure conditions, venting and contamination, quick disconnects, and standard fluid transfer interfaces.

### 4.3.2 Space-Based Low Energy Upper Stage

Technology development issues relevant to OMV are also shown, and development of fluid transfer and onorbit storage capabilities are considered crucial. In addition, for rendezvous operations, the development and use of Global Positioning satellite (GPS) hardware for OMV positioning, Tracking and Data Relay Satellite Systems (TDRSS) for target positioning and the development and validation of new guidance, navigation and control (GN&C) algorithms, are required. For remote docking of OMV with free-flyer satellites and platforms, demonstration of a ground-controlled, teleoperation docking capability is an additional technology challenge.

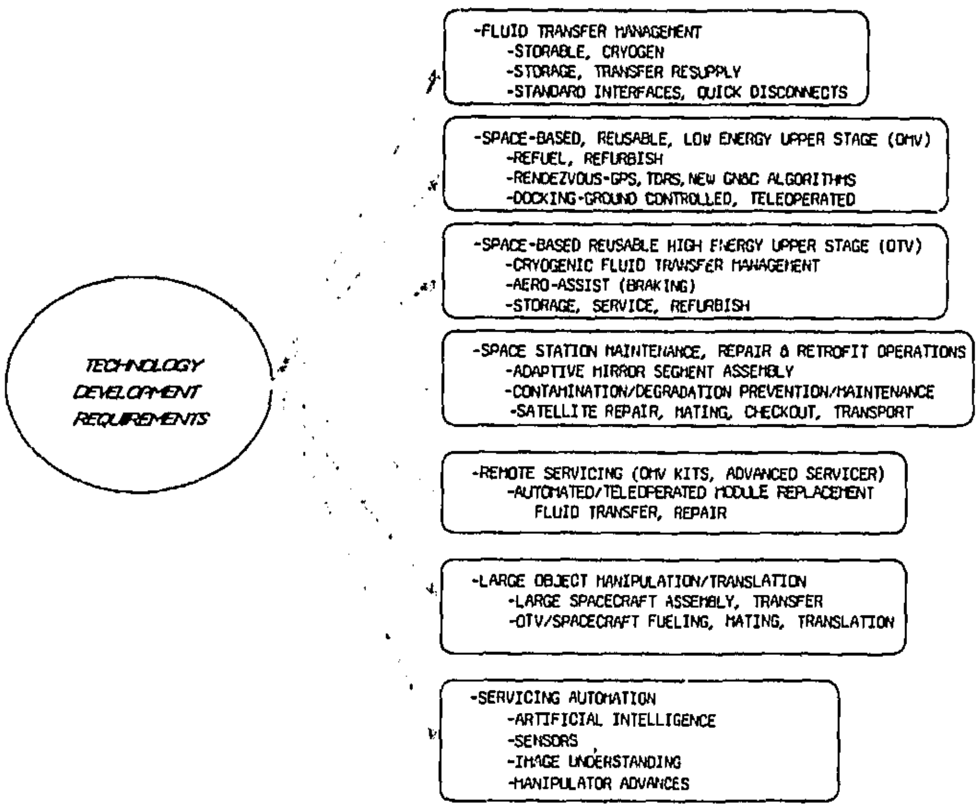


*Figure 4.3-1 Technology Development Overview*

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Table 4.3-1 Technology Development Requirements

-*FLUID TRANSFER MANAGEMENT*
- -STORABLES, CRYOGENS
  - -SUPPLY, STORAGE
  - -FLUID TRANSFER, RESUPPLY
  - -THERMAL, PRESSURE CONTROL
  - -SAFETY, VENTING, CONTAMINATION
  - -STANDARD INTERFACES, QUICK DISCONNECTS
  - -AUTOMATION FOR SAFETY, EFFICIENCY FOR REPETITIVE OPERATIONS

-*SPACE-BASED, REUSABLE, LOW ENERGY UPPER STAGE (OMV)*
- -FLUID TRANSFER-FUELS, PRESSURANTS, COLD GAS (FOR PROXIMITY OPERATIONS)
- -RENDEZVOUS-USE OF GPS HARDWARE FOR OMV POSITIONING/ TDRS FOR TARGET POSITIONING/NEW GN&C ALGORITHMS
- -DOCKING-OMV CAMERA USED TO ACHIEVE GROUND CONTROLLED TELEOPERATED DOCKING

-*SPACE BASED, REUSABLE HIGH ENERGY UPPER STAGE (OTV)*
- -CRYOGEN FLUID MANAGEMENT
- -AERO-ASSIST (BRAKING)
- -DESIGN FOR SERVICING
  - -MODULARIZATION-COMPONENT GROUPING
- -ADVANCED ENGINE
  - -PERFORMANCE, LIFETIME
  - -ADAPTIVE CONTROLS, HEALTH MONITORING, FAULT ISOLATION

-*REMOTE SERVICING (OMV KITS, ADVANCED SERVICERS)*
- -AUTOMATED/ROBOTIC OR TELEOPERATED MODULE REMOVAL & REPLACEMENT, SATELLITE REPAIR
- -AUTOMATED/ROBOTIC OR TELEOPERATED FLUID TRANSFER

-*ON-ORBIT MAINTENANCE, REPAIR & RETROFIT OPERATIONS*
- -ORU REPLACEMENT- ORU, LRU LEVELS
- -MIRROR ASSEMBLY REPLACEMENT
  - -ALIGNMENT, CONTAMINATION SHIELDING
- -CONTAMINATION/DEGRADATION PREVENTION/MAINTENANCE
- -ASSEMBLY OF ADAPTIVE MIRROR SEGMENTS
- -REUSABLE, SPACE BASED TRANSFER VEHICLE REFURBISHMENT
  - -AUTOMATED PROCESSES IN IOC TO ENHANCE SAFETY
  - -INCREASED AUTOMATION OF REPETITIVE OPERATIONS

-*LARGE OBJECT MANIPULATION/TRANSLATION*
- -TRANSLATION APPROACH
  - -MOBIL REMOTE MANIPULATOR SYSTEM-INCHWORM
  - -TRACKED-WHEEL BEARING, CABLE POWERED
- -INCREASED DEXTERITY
- -IMPROVED SENSORS
- -CAPABILITY OF TRANSPORTING LOADED OTV'S, ASSEMBLED SPACECRAFT
- -INCREASED AUTOMATION TO REDUCE EVA/SUPPORT SERVICING PRODUCTIVITY

Table 4.3.1 Technology Development Requirements (continued)

-SERVICING AUTOMATION

- ENHANCES-MAN'S PRODUCTIVITY, SAFETY, REPETITIVE OPERATIONS
- ARTIFICIAL INTELLIGENCE
  - PLANNERS-PATH, TASK
  - EXPERT SYSTEMS
  - NATURAL LANGUAGES, INTERFACES
  - ADVANCED DECISION ALGORITHMS
- SENSORS
  - COLOR STEREO CAMERAS
  - 3-D LASER IMAGER
  - PROXIMITY, TACTILE SENSORS
- AUTOMATED, AUTONOMOUS DOCKING
- COMPUTER VISION
  - IMAGE PROCESSING
  - PATTERN RECOGNITION
- MANIPULATOR ADVANCES
  - LIGHTWEIGHT, DEXTROUS ARMS
  - DUAL, MULTIPLE ARMS

### 4.3.3 Space-Based, Reusable High Energy Upper Stage

OTV technology development requirements were identified by review of documented OTV studies and was supported by insights obtained from the Martin Marietta OTV Phase A study team. OTV technology issues include cryogenic fluid management, an area in which Martin Marietta is presently heavily engaged. Denver Aerospace is presently proceeding in the detailed design of a Cryogenic Fluid Management Facility, intended to provide an onorbit facility for exploration and resolution of cryogenic fluid management issues. The design and development of an aero-assisted brake is considered essential, to reduce fuel requirements for OTV missions and inherently increase allowable payload weight for transfer to high energy orbits.

### 4.3.4 Remote Servicing

Technology development for remote servicing includes the technology required for either robotic or teleoperated module removal, satellite repair and fluid transfer. Remote controlled alignment, docking, and connection of fluid transfer devices are tasks requiring technology development, equipment definition and onorbit validation. Remote servicing technology development requirements generated by TDM1 include teleoperated or autonomous docking of OMV and teleoperated module replacement.

An alternative approach to module replacement at the MPP is to use an intelligent front end servicer on OMV to replace modules, rather than designing an MPP RMS for this task. The OMV intelligent front end imposes technology development requirements in the advanced automation area, including manipulator and sensors.

### 4.3.5 Onorbit Maintenance, Repair & Retrofit (MR&R) Operations

Onorbit maintenance and repair operations at Space Station, as detailed by the five selected TDMs, will become increasingly complex, requiring significant technology development. A legacy of MR&R experience will be developed and expanded with evolving servicing experience in STS operations. New equipment and maintenance procedures and techniques will be created to deal with onorbit servicing operations, similar to the repair of the Solar Maximum satellite and the retrieval of Palapa and Westar communication satellites.

Contamination and degradation of spacecraft surfaces, resulting from atomic oxygen and other elements in the space environment, will require development of both preventive maintenance and repair/refurbishment operations at the Space Station. With life expectancies from 15 to 30 years, Space Station and long term large satellite systems such as Space Telescope and AXAF will experience contamination/degradation of surfaces exposed to the natural and self-induced environments onorbit; i.e., engines, vents, outgassing, ultraviolet (UV), electrons, protons, atomic oxygen, etc. The development of technologies for cleaning, resurfacing

and recoating of affected surfaces must be addressed to enable servicing onorbit. A number of active high energy refurbishment systems are currently being considered. These include the use of; 1) a laser for removal of silicon-based materials, 2) a high energy oxygen beam system for hydrocarbon-based deposits, and 3) an ion beam (inert gas) sputtering system for recoating of various surface materials. Programs such as Space Telescope and AXAF are considering restoral of antennae and solar panels, using either replacement or refurbishment, during regular planned onorbit servicing operations.

One of the most challenging space servicing technology development requirements is in the area of the assembly of large adaptive mirror segments, such as for the Large Deployable Reflector (LDR). Course and fine alignment of the segments, mating and latching, either manually or automatically will require substantial technological advancement, especially when mirror surfaces must remain contamination free.

Finally, the refurbishment of reusable transportation vehicles, including the OMV and OTV, imposes additional technology development requirements on servicing planners. The transfer vehicles must be designed for onorbit repair and parts changeout. For OTV, the onorbit replacement of large engines and large aerobrakes will require special handling equipment and new techniques. These activities will require significant EVA time and will eventually become routine and repetitive, suggesting the need for increased automation.

The conduct of onorbit MR&R operations will require a substantial and varied set of basic technology development requirements.

### 4.3.6 Large Object Manipulation and Translation

The servicing scenarios evaluated in the study all require an effective means of moving large and small items around the servicing support area. A mobile, translatable manipulator system is a specific technology development requirement to support servicing operations. These manipulators must provide increased dexterity and improved sensors, to provide access in clearance restricted servicing zones. Heavy lift requirements are imposed by the need to move large spacecraft and OTVs around the station. Finally, increased manipulator automation will be required to enhance man's productivity in servicing operations.

### 4.3.7 Servicing Automation

In general, automation technology development requirements are driven by the need to; 1) improve continually the productivity of man in servicing operations, 2) continually enhance safety of operations, and 3) automate actions conducted frequently and repetitively. The technology development requirements are captured entirely by TDM5 and are summarized in Table 4.3-1.

## 4.4 STS Flight Experiments

During TDM Definition, STS flight experiment requirements were also established and maintained in a specific data base. This data base is presented in Figure 4.4-1. These candidate STS flight experiments were tabulated as each TDM was analyzed and defined in detail. Flight experiments were recommended to validate onorbit any precursor activities, technology development or servicing hardware/equipment, associated with servicing needs. This candidate STS flight experiment data base was evaluated following completion of TDM Detailed Definition and seven experiments were selected for expanded definition. They are listed as follows:

- Space Station proximity operations and docking/berthing demonstration
- Space Station contamination investigation
- Storable fluid management demonstration reflight
- Propulsion module refueling demonstration
- Servicer module changeout demonstration
- Servicer propellant transfer demonstration
- Tethered external tank (ET) deorbit demonstration

The definition of each of the STS flight candidates was expanded to include; technical approach, equipment requirements, schedule and funding.

### 4.4.1 Space Station Proximity Operations and Docking/Berthing Demonstration

The objective of this Shuttle flight experiment is to develop and demonstrate techniques for OMV proximity operations with Space Station, and to test adaptors and techniques for docking the STS orbiter and OMV to the Space Station. The OMV and the Orbiter will be integral elements of the Space Station system, and the safe interaction of these elements must be demonstrated. Docking/berthing techniques and adapters need to be developed for OMV and the Orbiter, and safe control of OMV by the Space Station needs to be demonstrated.

To simulate Space Station control of OMV, the OMV will be deployed from the Orbiter and flown in Orbiter proximity by an operator in the Aft Flight Deck. The handoff between ground and Space Station control could be demonstrated. OMV would then be flown within the RMS reach envelope to begin a simulation of OMV retrieval by Space Station. The RMS would attempt to retrieve OMV and berth it to an OMV-SS docking/berthing adapter, supported on the MMS Flight Support Structure.

**Fluid Transfer**

| | |
|---|---|
| Cryogenic Fluid Storage Tank/Offload to S/C | 1987-8 |
| Transfer OTV Storage Tank to Orbit/Resupply OTV | 1992-3 |
| Propellant Delivery to Orbit-ET//ACC/OMS Capture | 1986-7 |
| Hydrazine Transfer-Cargo Bay | Planned |
| PH-I/Mark II Fluid Transfer | Planned |
| Checkout of Standard Propellant Transfer Interface Module | 1985-6 |
| Earth Storable Storage Tank/Offload to S/C | 1985-6 |
| Propellant Delivery to Orbit-ET/ACC OMS Capture | |
| Cryogenic Fluid Management Facility Tests | Planned |

**[illegible]**

| | |
|---|---|
| OMV/Space Station Proximity Flight Control | 1986-91 |
| Space Station Assembly Demonstration | 1987-88 |
| Formation Flying with the Space Station | 1980-91 |
| OMV Docking and Berthing Development | 1991-92 |
| OMV/OTV Servicing Demonstration in Space Refueling/Mating | 1992-93 |
| Space Station Platform Refueling Demonstration | 1988-9 |
| Tethered Fuel Depot Demonstration | 1990-91 |
| Space Station Orbiter Docking Demonstration | 1988 |
| Aft Cargo Carrier Retrieval Demonstration | 1989-90 |
| Space Station Contamination Evaluation | 1987-8 |
| OMV Refurbishment/Checkout Demonstration | 1909 |

<u>Servicers</u>

| | |
|---|---|
| UMV/Servicer Mating Demonstration | 1989-90 |
| OMV/Servicer Module Changeout | 1991-2 |
| OMV/Servicer Propellant Transfer | 1991-2 |
| UMV/OTV Refurbishment Demonstration | 1989-93 |
| Resupply of Materials Processing System at Remote Locations | 1990 |
| Validate all Servicing Activities anticipated for Typical Repair/Refurbish Missions (AXAF, GRO, ST) | 1991 |
| Test of General Purpose Spacecraft Servicer (Payload Carriage/Carousel Mechanism and General Purpose Tools) | 1992-3 |

<u>Space Station Assy Modification</u>

| | |
|---|---|
| Space Station Service Area/Track/RMS Demonstration | 1989-90 |
| Deployment, Growth, Maintenance Demonstrations | 1988-9 |
| Assembly, Growth, Maintenance Demonstrations | 1988-9 |
| Transfer, Large Body Dynamics Tests | 1988-9 |
| Validation, Servicing (Aerobraking, Propulsion, Power Systems) | 1988-9 |
| MMU, EMU, OMV, OTV Outgassing Evaluation - Use Trailing CMV to Measure | 1987-90 |
| Control Method Evaluation - Cleaning, Cold Traps, Purge Concepts | 1988-9 |

<u>Spacecraft On-Orbit Assy</u>

| | |
|---|---|
| On-Orbit Validation of Spacecraft Assembly Tools | 1989 |

<u>Mating/Docking</u>

| | |
|---|---|
| Validation of OMV/Spacecraft Stacking | 1989-90 |
| Validation of Demating of OMV/Spacecraft, Demating in Vicinity of STS | 1989-90 |

*Figure 4.4-1 STS Flight Experiments*

Finally the Orbiter-SS docking/berthing adapter would be attached to OMV and the OMV would be flown to a standoff distance to begin the Orbiter-SS docking demonstration. OMV would stabilize itself and the docking/berthing adapter to simulate the Space Station, and the Orbiter would attempt to rendezvous and dock with its adapter. While the experiment scenario described here occurs in one STS flight it could be broken into several flights, if desired, to make demonstrations more manageable.

The equipment shown in Figure 4.4.1-1 is that required to complete this demonstration. The majority of the $25 million cost would go toward design, development, and integration of the Aft Flight Deck OMV control station. Much of that work would be directly applicable to the Space Station OMV control facility. The quoted cost assumes the MMS Flight Support Structure and the docking/berthing adapter are NASA furnished equipment. Flight data for the demonstration is early 1990.

### 4.4.2 Space Station Contamination Control

The objective of this Shuttle Flight Experiment is to determine the cause of the material degradation and induced glow witnessed so far on STS flights. These phenomena have serious implications for Space Station. Induced glow will corrupt data from spectral sensors on Space Station, reducing Space Station benefits to the remote sensing and astronomy communities, and materials degradation may affect any space station materials exposed to orbit gas flow, resulting in contamination of the Space Station environment. The mechanisms whereby materials degradation and induced glow occurs must be characterized and understood in order to determine fixes or select alternate materials.

An experiment package to carry out this investigation would include an array of test materials and a diagnostics package. The materials array could be articulated or the orbiter attitude could be varied to test angle of attack effects. Also, orbiter altitude could be varied to determine the affect of atmospheric density. The diagnostics package would examine each material in the array with a mass spectrometer to determine atomic species, a high resolution photon spectrometer to analyze glow signatures, and a plasma diagnostics package to survey the charged particle environment near each material (e-, p+, 0+, $O_2^+$, $N_2^+$, $H^+$, etc). The diagnostics package could be attached to or near the materials array, or it could be maneuvered by the RMS. It would be roughly half the size of the Plazma Diagnostics Package (PDP), flown on he STS in 1982.

The equipment required for the flight experiment includes the Shuttle, an array of materials of interest (described earlier) for contamination investigation, and the diagnostics package. The cost of the flight experiment is estimated at $10 million and could be flown in late 1988. This investigation provides the benefit of onorbit examination of the test materials as opposed to postflight examination on the ground, avoiding contamination that occurs as the Orbiter reenters the earth's atmosphere.

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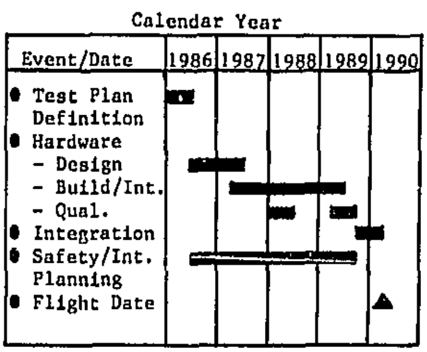
EQUIPMENT:
- STS ORBITER AND OMV
- ORBITER - SPACE STATION DOCKING/BERTHING ADAPTOR
- OMV - SPACE STATION DOCKING/BERTHING ADAPTOR
- MMS FLIGHT SUPPORT STRUCTURE
- INTERFACE FROM OMV TO ORBITER - SPACE STATION DBA
- AFT FLIGHT DECK OMV CONTROL STATION

SCHEDULE AND FUNDING:




1986 - $2.0M
1987 - $3.5M
1988 - $5.5M
1989 - $7.0M
1990 - $7.0M

TOTAL $25.0M

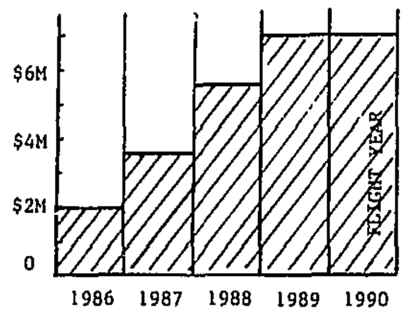



*Figure 4.4.1-1 Space Station Proximity Operations and Docking/Berthing Demonstration*

### 4.4.3 Storable Fluid Management Demonstration Reflight

The Storable Fluid Management Demonstration Reflight is specifically a recommended follow-on (or set of reflights) of the original SFMD.

The initial fight of the SFMD equipment is still scheduled for an STS flight in 1984. The existing SFMD facility is shown in Figures 4.4.3-1 and 4.4.3-2, and represents an opportunity to test many fluid transfer and propellant tank technologies that would directly support Space Station servicing. The initial SFMD experiment involves fluid transfer tests using a capilliary-type propellant management device (PMD), consisting of screen covered channels and cells formed by barriers and baffles.

The objective of this Shuttle Flight Experiment is to investigate an alternate capillary device in the receives tank of the two tank demonstration set up. The existing SFMD represents an opportunity to test many fluid transfer and propellant tank technologies that would apply to Space Station. These tests could be performed inexpensively and more effectively than can be done on the ground with techniques such as drop towers. The long time in zero-gravity allows detailed real time examination and adjustment of ongoing experiments. Since capillary devices are specifically tailored to a mission, there are numerous configurations of interest for which little or no filling and expulsion data exists.

The existing SFMD capillary device consists of screen covered channels and cells formed by barriers and baffles. The capillary device of interest that would be tested on this reflight has a sheet metal structure that uses the surface tension of the liquid in crevices of the structure to position liquid over the tank outlet. This device has the potential to allow venting of the tank as it fills. The experiment would examine the static liquid orientation, sensitivity of the liquid to disturbances, and performance during refill and expulsion.

The support equipment required for the SFMD reflight includes the STS onorbiter, the SFMD and the selected alternative capillary device. The estimated cost of the reflight is $0.3 million and could be flow in 1985.

### 4.4.4 Propulsion Module Refueling Demonstration

The objective of this Shuttle Flight Experiment is to demonstrate the on-orbit transfer of real propellant to an existing propulsion module using automated or EVA umbilical connection and standardized refueling interfaces. A large part of the servicing function on Space Station will involve refueling satellites, propellant servicers, and propulsion stages. This capability must be developed and demonstrated. The Propellant Transfer System as well as standardized umbilicals and interfaces utilized in this demonstration could easily be adapted to Space Station as an operational refueling system and could also form the basis for development of a propellant servicer.

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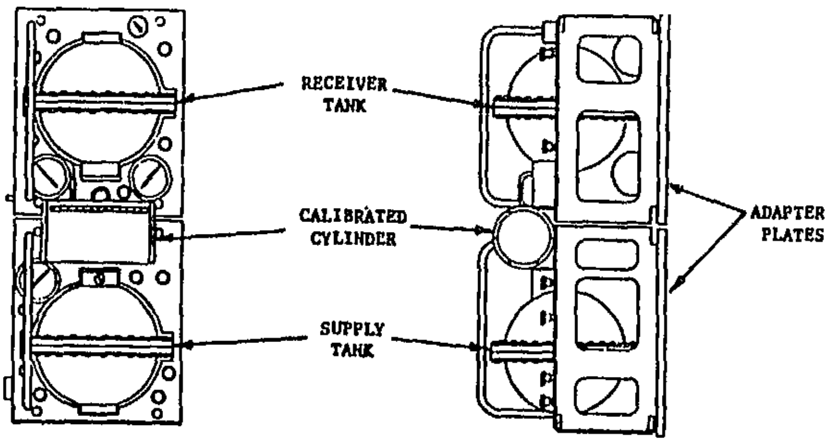


*Figure 4.4.3-1 SFMD Configuration*

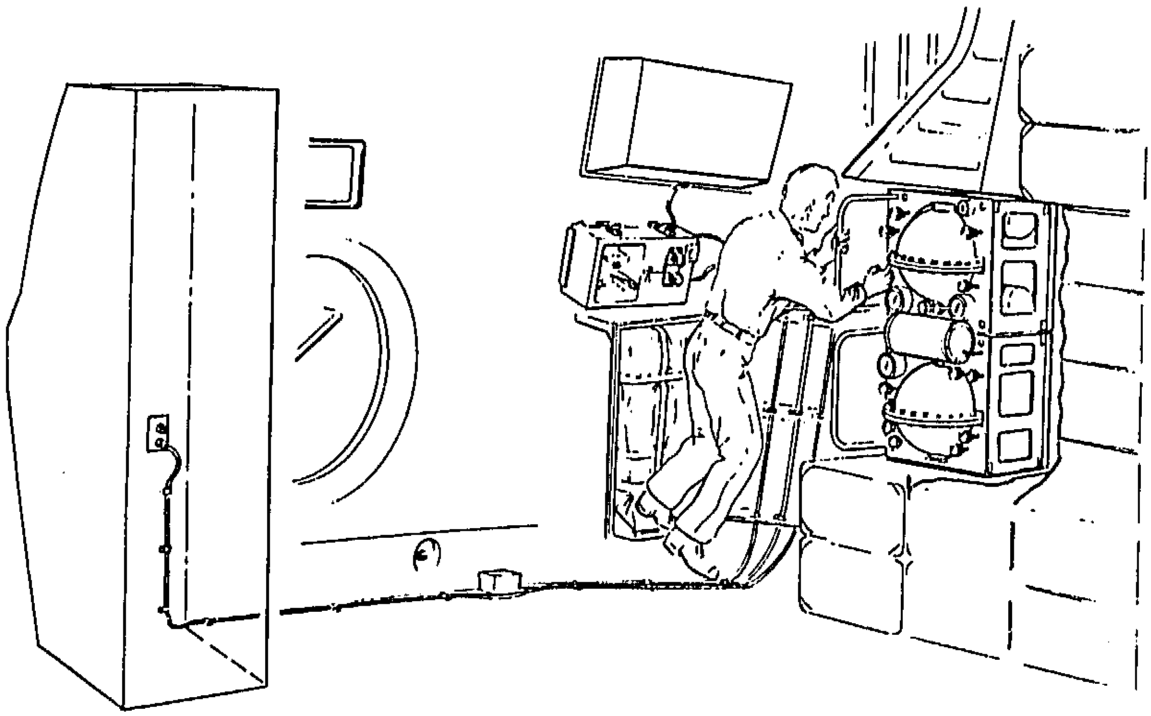

*Figure 4.4.3-2 Storable Fluid Management Demonstration - Orbiter Mid-Deck*

As shown in Figure 4.4.4-1, a Mark II Propulsion Module would be supported on the MMS Flight Support Structure, and propellant would be transferred to it from a Propellant Transfer System (PTS) through standardized umbilicals and interfaces. The refueling interface (umbilical connection device) would be connected to the Propulsion Module either by an EVA astronaut or an automated mechanism. This demonstration would essentially eliminate the need to demonstrate OMV refueling since the interface from the PTS to the Propulsion module is the same.

This experiment is considered an appropriate follow-on to the cargo bay hydrazine transfer experiment conducted in October, 1984.

The equipment required for this demonstration is shown in Figure 4.4.4-2. The Propellant Transfer System would consist of a Mk II Propulsion Module cradle and components housing from 4 to 7 Shuttle RCS tanks. The cost cited assumes the MMS Flight Support Structure and standardized umbilicals and interfaces are NASA furnished equipment. It also assumes the demonstration is flown in late FY 1987 to take advantage of Mk II PM program timing. Use of Mk II must be negotiated with the Air Force.

### 4.4.5 Servicer Module Changeout Demonstration

The objective of this Shuttle Flight Experiment is to demonstrate the servicer capability to changeout modules, including batteries, from a simulated spacecraft. This Space Station satellite servicing function will include the requirement to service satellites remotely through module changeout by an intelligent servicer, and this capability must be demonstrated.

To carry out this demonstration, the RMS will grapple and maneuver a simulated spacecraft to a docked position with a stowage rack/servicer which is supported on the Multi-mission Modular Spacecraft (MMS) Flight Support Structure. The Initial Onorbit Servicing System (IOSS) arm on the servicer will then demonstrate automated module changeout capability, transferring modules from the stowage rack to the simulated spacecraft and back. This experiment provides the additional benefit of simulating servicer to spacecraft docking.

The equipment required for this STS flight experiment is shown in Figure 4.4.5-1, and includes the STS orbiter, a simulated spacecraft, a stowage rack/servicer with an IOSS, the MMS flight support structure and replacement modules. The cost of the flight experiment is estimated at $15 million and could be flown in 1988.

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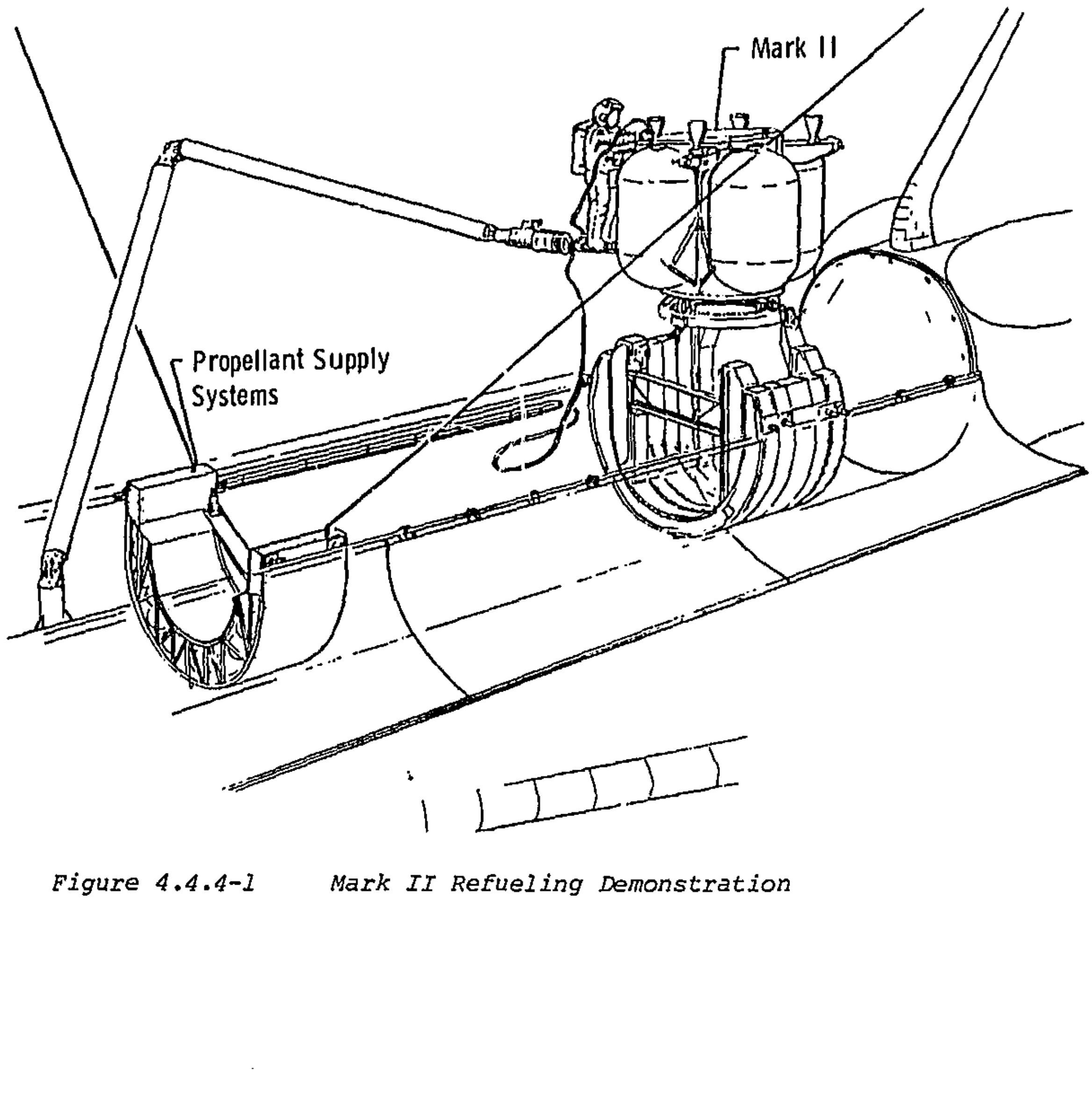
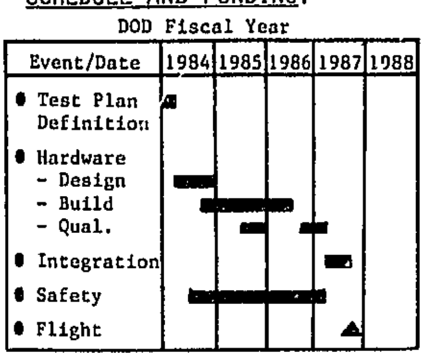



*Figure 4.4.4-1 Mark II Refueling Demonstration*

EQUIPMENT:

- STS ORBITER
- MK II PROPULSION MODULE
- PROPELLANT TRANSFER SYSTEM
  - MK II PM CRADLE AND COMPONENTS
  - 4 TO 7 SHUTTLE RCS TANKS
- STANDARDIZED UMBILICALS AND UMBILICAL CONNECTION MECHANISMS
- MMS FLIGHT SUPPORT STRUCTURE

SCHEDULE AND FUNDING:




FY 1984 - $ 2.0M
FY 1985 - $ 3.0M
FY 1986 - $ 3.0M
FY 1987 - $ 2.0M

TOTAL - $10.0M

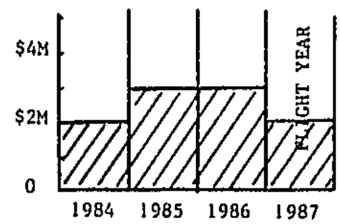



*Figure 4.4.4-2 Propulsion Module Refueling Demonstration*

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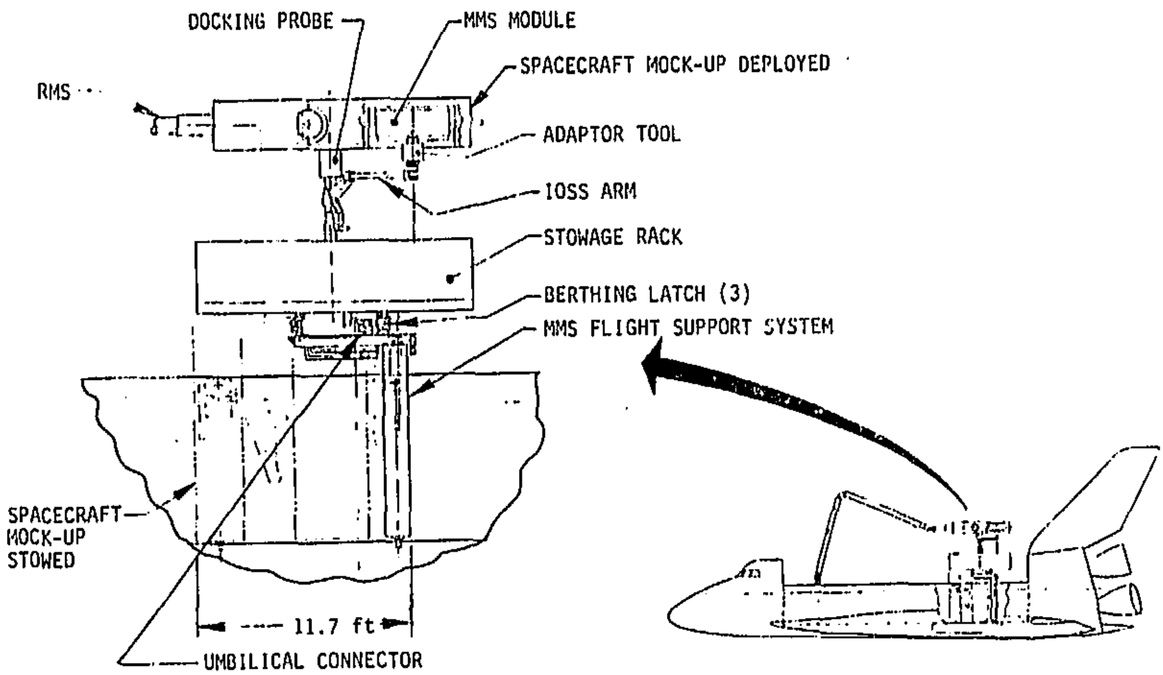


*Figure 4.4.5-1 Servicing Flight Demonstration Using RMS*

### 4.4.6 Servicer Propellant Transfer Demonstration

The objective of this shuttle flight experiment is to demonstrate servicer capability to refuel a simulated spacecraft through automated tank changeout or propellant transfer. Part of the Space Station servicing function will include remote spacecraft refueling with a propellant servicer, and this servicer capability must be developed and demonstrated.

The propellant transfer flight experiment will follow, and use some equipment from, the servicer module changeout experiment. In place of modules, fuel tanks will be automatically transferred from a stowage rack/servicer to a simulated spacecraft and back using the IOSS arm. Also, automated propellant transfer capability will be demonstrated by using the IOSS arm to connect a flexline umbilical from a tank in the stowage rack/servicer to a tank in the simulated spacecraft, transferring propellant through the flexline umbilical.

The equipment required is illustrated on Figure 4.4.6-1. The cost to conduct this servicing STS flight demonstration is estimated at $8 million assuming the MMS Flight Support Structure is NASA furnished equipment and could be flown in 1989.

### 4.4.7 Tethered External Tank (ET) Deorbit

The primary objective of this Shuttle Flight experiment is to demonstrate a tethered ET deorbit; however, it also has the Space Station related objective of demonstrating tether orbital dynamics effects and basic tether handling techniques for large tethered masses. A tethered ET deorbit has the potential to increase STS payload capability to orbit and increase STS launch azimuth flexibility. Since the ET may be dropped at any time once it is in orbit with the Shuttle, the ET reentry constraint on launch azimuth can be reduced. Also Space Station will very likely take advantage of the benefits of tether techniques by using tethered space platforms, tethered logistics operations with STS, or tethered energy management systems. These techniques require development and demonstration, particularly the handling of tethers with large masses attached.

To perform this experiment, an ET would first be carried into a low earth circular orbit (TBD Nm) and a tether would be attached either before launch or before ET separation. The Orbiter would begin to separate to generate tension on the tether, and, as the tether reels out, the ET would fall below the initial orbit and the Orbiter would rise above the initial orbit (cg remains at the initial orbit). The tether would stop reeling out at around 30 to 40 Nm in length, and the ET would be dropped at an appropriate point. An attitude control system on ET similar to that proposed for the Aft Cargo Carrier would maintain control of the ET during tether operations and during at least part of the reentry.

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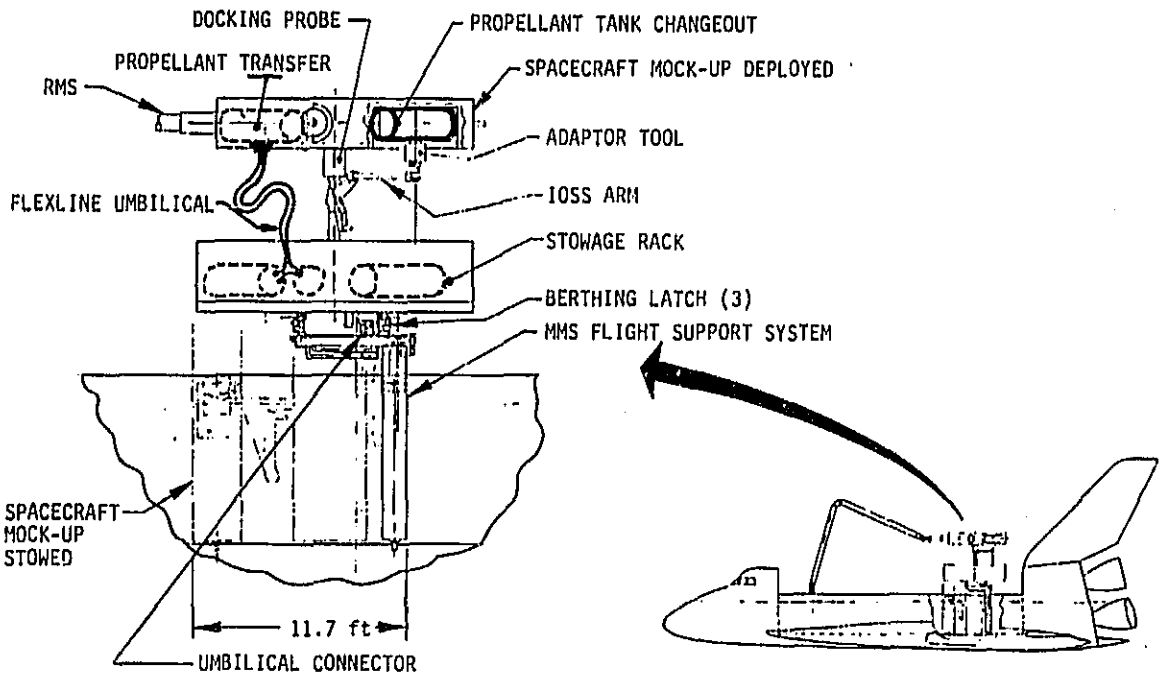


*Figure 4.4.6-1 Servicing Flight Demonstration Using RMS*

This demonstration would provide experience in handling large tethered masses as will likely exist on Space Station, and the equipment required to carry it out includes the STS Orbiter, the ET, a tether and tether management system, and an attitude control system (ACS) for ET. The experiment could either be performed in one flight as described previously, or it could be performed in two flights with a precursor experiment that would demonstrate ET deorbit operations with a smaller test payload. ET deorbit flight experiment is estimated at $10 Million and could be flown in 1988.

## 4.5 Technology Development and STS Flight Experiment Plan

The Technology Development and STS Flight Experiment Plan, hereafter referenced as the TD&FE Plan, is a time phased sequence of technology development and flight validation activities leading to development of servicing capabilities. The genuine development of an implementable plan is considered well beyond the scope of this contract. However, the technology development data base and the STS flight experiment data, combined with additional estimates of required Space Station flight experiments has provided information enabling the generation of realistic outlines of a TD&FE Plan. This type of plan is shown on Figure 4.5-1. This plan highlights the top level technology activities essential to demonstration of TDM 2, the retrieval and repair of the Advanced X-ray Astrophysics Facility. It addresses technology related to three of the seven areas identified previously in Paragraph 7.3, Vol I, Technology Development Requirements; i.e., fluid transfer management, the space-based reusable low energy transport vehicle (OMV), and onorbit maintenance, repair and retrofit operations. A similar plan, covering advanced automation and OTV was provided in the detailed definition of TDM 5.

Referring to Figure 4.5-1, for technology development in the area of fluid transfer management, NASA has scheduled the initial flight of a Storable Fluid Management Device (SFMD) on an upcoming STS flight. This is an aft flight deck experiment consisting of two tanks, a supplier and receiver tanks with visible panels to observe and photograph fluid transfer operations under varying conditions. Follow-on flights for the SFMD are recommended to evaluate other propellant management devices (PMD) and other fluid transfer technology issues.

A fluid quick disconnect (QD) for onorbit refueling of the Gamma Ray Observatory (GRO) is in planning and will be supplied to the GRO developer by mid-1986. An STS flight experiment will validate the QD. Planning is also underway in NASA for development of a standard propellant transfer interface device. Ground development is expected to begin in 1985, with flight test of a manually connected (EVA) device in 1987, and an automated device flight tested in 1989.

For OMV, the present development schedule is shown and fluid transfer tests are not required prior to flight test in 1990. An OMV resupply flight experiment is scheduled during 1990. The schedule for rendezvous and docking ground development, STS flight tests and Space Station validation tests are also provided. In addition, retrieval operations are scheduled, beginning with PALAPA/WESTAR later accomplished this year, and including LANDSAT and SPACE TELESCOPE, all by STS. An OMV retrieval is scheduled with the first launch from STS, with validation flights at Space Station following completion of OMV accommodation on Space Station.

(SUPPORT FOR TDM2 - AXAF RETRIEVE/REPAIR)

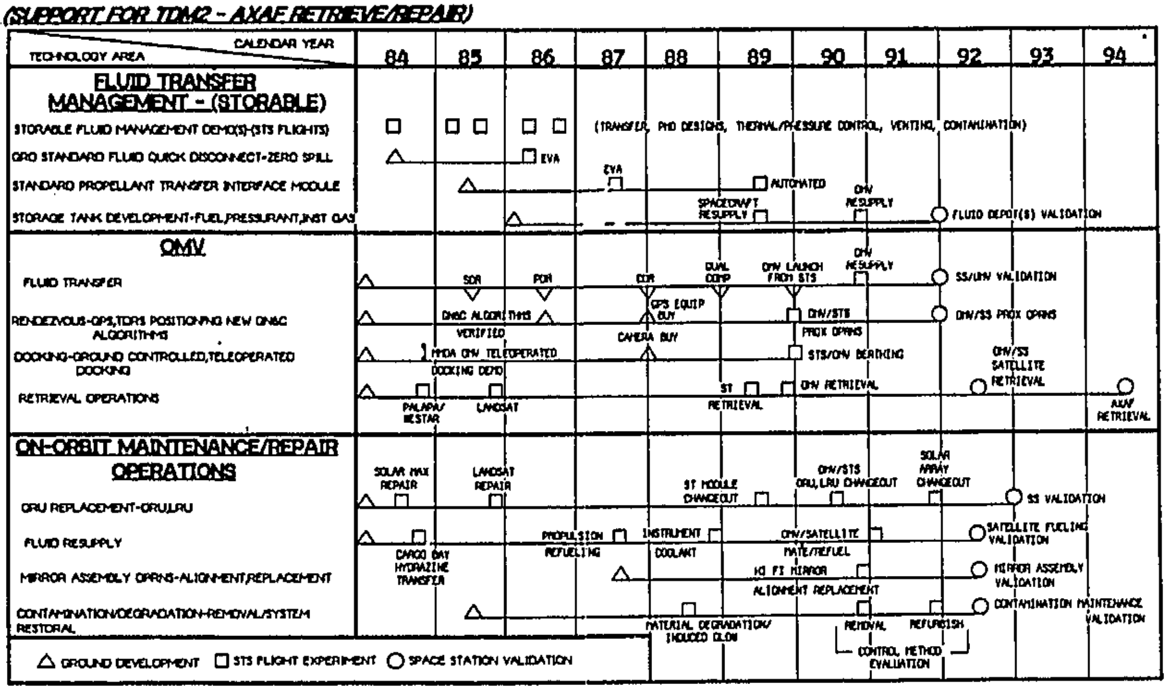


*Figure 4.5-1* *Technology Development and STS Flight Experiment Plan*

The onorbit maintenance and repair technology schedule includes development and validation of ORU replacement operations, fluid resupply, mirror assembly replacement (for AXAF), and contamination/degradation removal and system restoral operations. Fluid resupply development is already underway and an STS cargo bay hydrazine transfer was conducted in October, 1984. The Mark II propulsion transfer experiment, previously discussed, is recommended for STS flight in 1987. Following development of OMV and OMV tanker kits, an OMV/satellite refueling is scheduled in 1991, and follow-on Space Station validation of OMV operations and refueling at a storable fluid depot.

In general, all technology development trails lead to a series of appropriate STS flight tests, and Space Station validation tests prior to servicing of AXAF in 1994, as outlined in the Technology Development and STS Flight Experiment Plan.

## 5.0 PROGRAMMATIC ANALYSIS

The programmatic analyses for Phase 2 of the servicing study included; development of a summary TDM schedule, an evaluation of the cost of each TDM, and finally, an estimate of the spread of costs across the summary TDM schedule.

### 5.1 TDM Schedule

The TDMs were scheduled independently, using realistic technology development schedules and existing program planning schedules including those for Space Station, OMV, OTV, EOS, and LDR. The TDM schedule is displayed in Figure 5.1-1. The test-bed role of the Space Station as a base for demonstrating evolutionary satellite servicing capabilities is strongly supported by this schedule.

Space Station modification, TDM 3 is the first of the five selected TDMs scheduled for implementation. Planning for any TDM assembly operation involving modification of the Space Station will be initiated early in Space Station definition efforts, and will include tracking of all identified precursor activities. The scheduled mission is expected to be conducted during the latter phase of evolution leading to an IOC.

TDM 1 is the second scheduled mission and will take place following Space Station development, Materials Processing Platform development, and validation of OMV front end servicer kit operations. The late 1993 schedule for this TDM appears reasonable and realistic. It can be scheduled earlier if the requisite precursor activities are complete.

TDM 2, the AXAF retrieval and repair mission, could be conducted early, as described previously, if precursor activities are completed, and major malfunctions occur in an orbiting AXAF system. Otherwise, the mission will be conducted per the present AXAF program schedule.

TDM 4, the onorbit assembly of the Large Deployable Reflector is presently planned for the 1997 timeframe. The time-phasing for TDM5, demonstration of the Intelligent Servicer, is to consolidate evolving automation advances in 1991, and to develop a semi-autonomous, supervisory controlled servicer for demonstration in 1997.

### 5.2 TDM Cost Analysis Activities

A complete cost analysis was performed on each of the five Satellite Servicing TDMs. A summary of TDM costs is shown in Table 5.2-1. Each of the TDM cost elements were identified. These cost elements fell under three categories: a) user's cost elements, b) TDM unique cost elements, and c) space station common cost elements. Figure 5.2-1 shows cost element breakdowns for TDM1 to examplify what was done for all the TDMs. Users's cost elements are areas that the mission user i.e., MPP, AXAF, and other satellite projects, have or will account for in their process of development . Such elements include the MPP modules, the AXAF ORUs, the Large Spacecraft itself, etc. The TDM mission unique costs, are cost elements that the satellite servicing mission will stand accountable for such as mission training for the crew, OMV and OTV refurbishment, etc.

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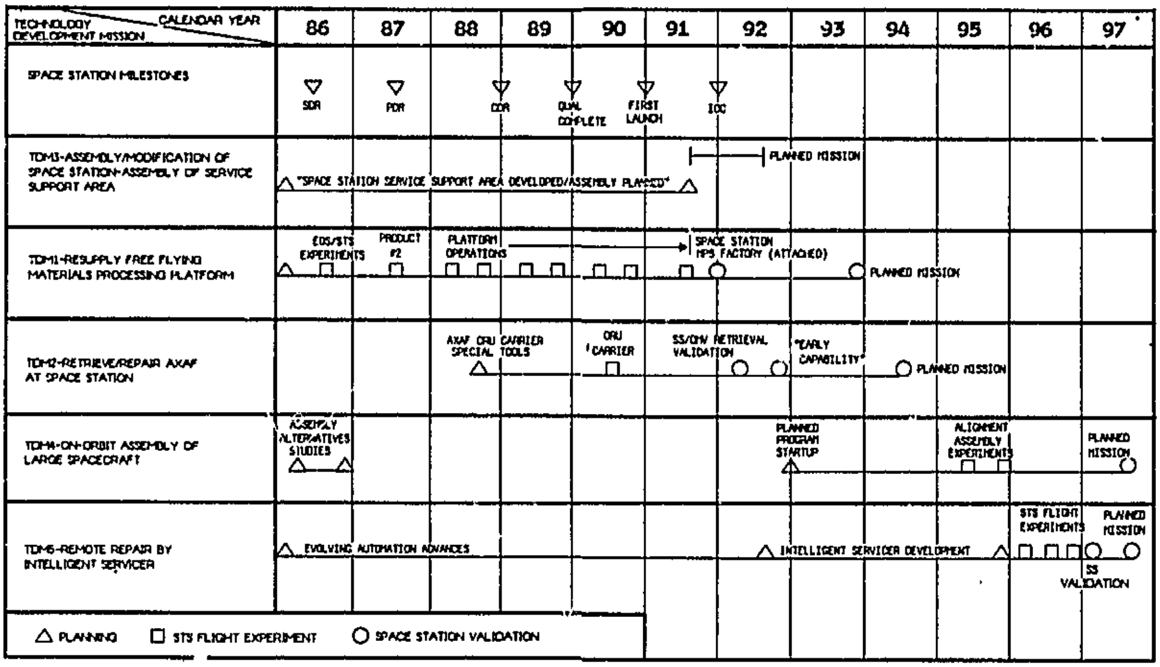


*Figure 5.1-1* *TDM Schedule*

*Table 5.2-1* *Satellite Servicing - TDM Cost Summary*

1984 $ IN MILLIONS

| TDM | TDM-SPECIFIC COST | MAJOR COST DRIVER(S) |
|---|---|---|
| 1 - RESUPPLY MPP | 7M | SPACE CREW TRAINING, OMV FUEL TRANSPORTATION COSTS |
| 2 - RETRIEVE/REPAIR AXAF | 17M | TDM2 SUPPORT EQUIPMENT, SPACE/GROUND CREW OPS., OMV FUEL TRANSPORTATION COSTS |
| 3 - SATELLITE SERV. SUPPORT AREA ASSEMBLY | 278M | STS DELIVERY COST FOR CANISTER, STS CARGO CANISTER COST |
| 4 - ASSEMBLY OF LARGE SPACECRAFT | 60M | SPACE CREW TRAINING, SPACE CREW OPS/ASSEMBLY |
| 5 - REMOTE REPAIR BY INTELLIGENT SERVICER | 189M | INTELLIGENT SERVICER COST, OTV FUEL TRANSPORT COST |

COST ELEMENTS

**MPP UNIQUE COSTS**

- MODULES
- MODULE TRANSPORT (FROM/TO GROUND)
- MODULE STORAGE
- MODULE RESUPPLY SERVICER
- SERVICER BERTHING FACILITY
- RMS ON MPP
- MPP WITH TEMPORARY STORAGE RACK
- COMMUNICATIONS EQUIPMENT (ON MPP)
- PLANNING FOR MPP SERVICING IS MPP COST

**TDM1 COSTS**

- TRAINING FOR MISSION
- ENGINEERING AND TECHNICAL SUPPORT
- OMV REFURBISHMENT
- SPACE CREW TIME
- OMV OPERATIONS (FUEL USAGE)

**SPACE STATION COMMON COSTS**

- OMV REFURBISHMENT FACILITY
- OMV BERTHING FACILITY
- OMV FUEL DEPOT
- OMV OVERHAUL
- OMV SUPPORT EQUIPMENT
- RMS
- UMBILICALS
- MONITORING EQUIPMENT
- HANGAR FACILITY

*Figure 5.2-1 TDM 1 - Cost Elements*

The Space Station common cost elements are items that will be used for Satellite Servicing missions as well as for other Space Station related activities. The cost elements that were analyzed for the Satellite Servicing activities were those unique to each TDM only.

The conceptual status of each TDM prevented a more detailed cost analysis. The cost figures provided are only relative order of magnitude (ROM) costs, due to the lack of historical data availability.

## 5.3 Costing Approach

When all the pertinent cost elements for each mission were identified, a set of basic ground rules and assumptions was established prior to conducting the actual cost analysis, as shown in Table 5.3-1. The common groundrules and assumptions for all TDMs are: costs are in FY 1984 dollars and the relative order of magtitude (ROM) costs were based on the Cost Estimating Relationships (CERs) from Planning Research Corporation (PRC) systems services dated 1978. The cost analyses were broken into non-recurring and recurring ROM costs. The risks and concerns on each cost analysis was then summarized. The common risk and concern for all TDMs is the uncertainty in costing astronaut time based on utilization of the Space Station. This cost is projected at $30,000/hr based upon six crew members.

## 5.4 TDM 1 - Cost Analysis

The cost elements that were identified as part of this TDM for non-recurring are; space crew training, engineering and technical support, and OMV refurbishment, and for recurring; space crew time for the actual mission, and for OMV operations, such as fuel usage. Even though each TDM was analyzed for one mission only, most of these TDMs have recurring services. To denote that, mission frequency (i.e. every six months) mission duration (i.e. 13 hrs), and mission crew (i.e., three people) were outlined as basic groundrules and assumptions for TDM1. Some of the other ground rules and assumptions include the MPP co-orbiting location with Space Station, a fact which leads to the use of an OMV and accompanying OMV groundrules. The OMV is assumed to be a universal Space Station vehicle that will not need earth overhaul until approximately 50 missions have occurred. Since this is only one mission out of 50, the OMV earth overhaul is not costed and is really considered a space station cost. A 10 year life cycle cost is the basis for the OMV refurbishment cost calculations. These costs are based on possible parts replacement and percentage of usage, and thus they classify more as a one time cost rather than a recurring cost, since the reality of all possible failures to occur in one mission does not exist.

*Table 5.3-1* *Satellite Servicing Cost Analysis*

BASIC GROUND RULES AND ASSUMED COST FACTORS:

- 1984 $ IN MILLIONS
- SPACE STATION CREW OPERATING COSTS (IVA) BASED ON A SPACE STATION CREW OF 6 AND AN OPERATING COST OF $30,000/HR
- EVA CREW COSTS TAKEN FROM STS USER'S GUIDE - ASSUMED TO BE $17,500/HR/MAN
- HARDWARE COSTS DEVELOPED USING 1978 PRC SPACE STATION COST MODEL
- STS COST/FLIGHT ASSUMED AT $200M
- OMV FUEL ASSUMED TO BE STS DELIVERED AT A COST OF $2,000/LB
- SPACE CREW TRAINING IS ASSUMED AS A FUNCTION OF HARDWARE DDT&E AND PRODUCTION COSTS - FUNCTION IS GIVEN BY '78 PRC MODEL

The crew time for training for the missions was based on the assumption that four MPP factories will exist and will need module replacement. This training includes learning how to operate the OMV, how to operate the RMS on the MPP, and how to reprocess these modules. Total crew training for this mission is estimated at $2 million. The engineering and technical support included planning and implementation of the missions and is estimated at $1.5 million. Finally, the last non-recurring cost was the OMV onorbit refurbishment of $0.5 million.

The crew time of 13 hrs per mission is based on OMV mating with servicer, deployment, resupply of the MPP and refurbishment of the OMV. Crew time and labor is estimated at $0.5 million.

The IVA dollars/hr were based on an hourly cost for Space Station utilization of $30,000 for six people. The assumed IVA labor rate is $5,000/person. The other recurring cost of OMV operations is fuel usage costed at $2.5 million based mainly on an assumption (from STS Reimbursement Guides) of earth to orbit fuel launch costs of $2,000/lb. The fuel weight calculations were based on its orbital paths & loads.

Total TDM1 mission unique cost is estimated at $7 million.

## 5.5 TDM2 - Cost Analysis

The basic difference between TDM1 and TDM2 is that in TDM1 the OMV is used to replace modules on an orbiting platform, where as in TDM2 the OMV is used to retrieve the complete satellite, bring it to Space Station for repair and then return it to orbit. This mission is expected to be planned as an STS initial service and later transferred to a Space Station Satellite mission. This assumption is very important because it excludes from the TDM the costs of the initial AXAF research, development test and evaluation, crew training and servicing equipment, since most of it will be part of the STS costs. The space crew time involved in transfer of the servicing equipment is considered as a non-recurring cost of $0.5 million. Again, all AXAF operations involve three crewmembers. The crew time, in retraining, includes learning how to retrieve and repair AXAF. The training cost is based on the AXAF equipment that will be serviced and it is projected at $1 million. The engineering and support for planning and implementation of the mission is estimated at $0.5 million. Using the same assumptions and groundrules for the OMV as in TDM1 the refurbishment cost based on percentage usage over the OMV lifetime is expected to be $1 million. The support/servicing equipment estimated at $6.5 million is equipment other than that transferred from the STS. This equipment is unique to the AXAF Satellite Servicing mission and not Space Station common equipment such as the hangar facilities. This equipment also does not include the AXAF equipment to be replaced and serviced.

For the recurring costs, since AXAF is to be serviced approximately four times even though this analysis costs one mission only, key groundrule and assumption is that this mission will take approximately 156 hrs or 420 crew hrs. Of these crew hrs 96 hrs (or 48 hrs/crewmember) are EVA hrs in repairing the AXAF. The other 324 hrs (or 108 hrs/crewmember) were IVA hrs and the same cost analysis logic i.e., $5,000/person was used. The EVA dollar/hr is based on the NASA's "1980 JSC-11802-Reimbursement Guide for STS" which comes to $17,500/hr/crewmember. The total crewtime cost is projected at $3.5 million. Ground crew time cost was considered minimal and thus not included in this cost analysis. The OMV operations based on fuel usage are estimated at $4.0M.

The total TDM2 unique costs are estimated at $17 million.

## 5.6 TDM3 - Cost Analysis

This was a straight-forward cost analysis because the whole mission is a non-recurring, one time mission only. All the support equipment; i.e., RMS, communications etc. already exist as part of the Space Station. All assembly hardware is considered a Space Station cost because this mission involves extending the Space Station itself. This same groundrule applies to the engineering planning and support for the assembly process. The costs unique to the Satellite Servicing mission are the STS cargo canister, STS launches (only one), the training for the assembly and the actual assembly time. The crew training cost of $21 million is based on the hardware costs for the canister, the strongback, the service hangar, the fuel depot, the OMV berthing ring and the servicer storage. The STS cargo canister cost of $39 million is based on approximately 500 lbs of structure. Only one STS delivery of $200 million is charged to this mission. Other launch deliveries are considered Space Station costs because they are transporting Space Station extension hardware.

The total mission time is estimated at 361 IVA hrs/crewmember and 254 EVA hrs/2 crewmembers. The total assembly time cost is projected at $16 million.

The EMU, MMU refurbishment costs are based on percentage usage and parts to be serviced. These costs for the complete mission are estimated at $2 million.

Total costs for TDM3 are estimated at $278 million and are shown in summary form on Table 5.6-1.

*Table 5.6-1* *Satellite Servicing ROM Costs - TDM 3*

NONRECURRING

| | | |
|---|---|---|
| SPACE CREW TRAINING | | $ 21M |
| STS CARGO CANISTER | | $ 39M |
| ONE STS DELIVERY FOR THE CANISTER | | $200M |
| ASSEMBLY CREW TIME - IVA | | $ 6M |
| - EVA | | $ 10M |
| REFURBISHMENT COSTS EMU, MMU | | $ 2M |
| | TOTAL | $278M |

MAJOR COST DRIVERS - DELIVERY BY STS

## 5.7 TDM4 - Cost Analysis

Costing for this TDM was also very direct as the entire mission was considered a non-recurring one time only assembly of the LDR. Once the specific assembly steps were defined, the cost elements were identified. Cost elements included: the crew time in assembly and deployment, the space crew training in the assembly process, the OMV, EMU, MMU refurbishments and the OMV fuel usage. The research, design, test and evaluation, and planning for the assembly, the assembly procedure writing, the LDR hardware and the STS deliveries were all considered LDR unique costs and not Satellite Servicing mission costs.

The training for the assembly mission is $38 million and is based on the total hardware cost of the LDR and the tools used for the assembly. The crew time in assembly is estimated to be 604 IVA hours and 664 EVA hours. In this assembly, IVA hours are based on one crewmember inside and EVA hours are based on two crewmembers outside. The ground time cost was assumed to be minimal. The total crew time cost is projected at $15 million.

Since this mission involves the OMV for the orbiting of the LDR and the EMU and MMU for the assembling of the LDR, the refurbishment costs of these pieces of equipment are considered a Satellite Servicing cost and are estimated at $3M. The final cost is the OMV fuel usage which is projected at $4M.

Total TDM unique costs for TDM4 are estimated at $60 million.

## 5.8 TDM5 - Cost Analysis

This was the most difficult of the five TDMs to cost because of the significant elements of uncertainty included in it. The OMV groundrules & assumptions that were made for the other TDMs apply here also. Other groundrules & assumptions apply to the OTV operations, such as the OTV's universal usage, its two engines, the 45 missions prior to earth overhaul and the on-orbit maintenance for every 20 missions. This mission involves only IVA crew hrs and a lot of ground support. The total mission hrs were estimated at 166 hrs. This could be a recurring mission, however this cost analysis was performed on one mission only.

The training for the mission is mainly based on training for the Intelligent Servicer. The OMV & OTV training is not included because by this time frame (1997), the OMV & OTV will have been utilized for many other missions. The cost of training of $6 million therefore is based on the hardware cost of the Intelligent Servicer. In addition to mission training there will be some training exercises prior to the launch of the OTV/IS to geosynchronous orbit. These exercises were estimated at 144 hrs per crewmember and were projected at $2.5 million. The equipment refurbishment involves the two OMVs and the IS and is costed at $1.5 million. Again these costs are classified as non-recurring because they are based on the percentage usage of the equipment as applied to possible equipment failures. The OTV refurbishment was not included because it is not spread over the lifetime of the vehicle. It is rather based on an OTV maintenance schedule for the two engines, and therefore it is a recurring cost.

Some of the other remaining non-recurring costs include some servicing and monitoring equipment peculiar to the Intelligent Servicer, estimated at $4 million, and the engineering support planning and implementation for the mission, estimated at $6 million.

The Intelligence Servicer has been assumed to be a Satellite Servicing mission unique cost element rather than any satellite's cost element. Its launch to Space Station cost is therefore included and estimated at $24 million based on STS cargo area requirements. The Intelligent Servicer itself is costed at $75.5 million and it includes the manipulator arms, the stabilizers, the anchors, the frame, the umbilicals, the laser, and the computer system and sensors.

Recurring costs include the standard space crew and ground crew time costs based on about 220 total hrs of which 166 hrs per crewmember are for the mission itself. The labor cost is thus estimated at $3 million. The OTV fuel usage is estimated at $60 million (the OMV fuel usage is minimal). The last recurring cost is the OTV refurbishment based on the engine overhaul and a 15 hr maintenance schedule. This is estimated at $44M per mission.

The total mission unique cost of TDM5 is estimated at $189 million and the cost summary is shown on Table 5.8-1.

*Table 5.8-1* *Satellite Servicing ROM Costs - TDM 5*

| | |
|---|---|
| **NONRECURRING** | |
| • TRAINING OF SPACE AND GROUND CREW FOR THE MISSION | $ 6.0M |
| • IS MATING AND REPAIR TRAINING EXERCISES CREW TIME | $ 2.5M |
| • EQUIPMENT REFURBISHMENT - $OMV_1$, $OMV_2$, IS | $ 1.5M |
| • SUPPORT EQUIPMENT (MAINLY IS EQUIPMENT) | $ 4.0M |
| • ENGINEERING, MISSION PLANNING AND IMPLEMENTATION | $ 6.0M |
| • LAUNCHING OF IS TO SPACE STATION IN STS | $24.0M |
| • INTELLIGENT SERVICER (IS) | $78.0M |
| TOTAL | $122M |
| **RECURRING** | |
| • SPACE AND GROUND CREW TIME/MISSION | $ 3.0M |
| • OTV OPERATIONS COST/MISSION | $60.0M |
| • OTV REFURBISHMENT AND MAINTENANCE/MISSION | $ 4.0M |
| TOTAL | $ 67M |
| TOTAL TDM COST | $189M |

## 6.0 INDUSTRIAL SERVICING INTEREST ASSESSMENT

### 6.1 Introduction

The objective of this task was to determine the interest of potential commercial Space Station users in the services to be demonstrated on the early Space Station. The planned approach to this task was: 1) to develop a comprehensive overview of the cost, timing and capabilities that would be demonstrated by the TDMs, 2) to contact potential commercial space users and discuss study results; i.e., conceptual Space Station satellite servicing concepts, and 3) to determine commercial user needs and assess their interest in developing and using servicing capabilities at the Space Station.

Upon completion of all of the tasks previously discussed, a selected group of potential commercial users and others presently involved in studying concepts for commercialization of space, were contacted. This group of commercial user contacts is displayed on Table 6.1-1. The results of the commercial user assessment were generally very positive. Potential users expressed genuine awareness of and interest in the servicing potential at Space Station, and presented concerns and questions that will assist Space Station planners in developing servicing capability.

### 6.2 Commercial Payload Definition Studies

One of the first potential commercial servicing sources examined by Martin Marietta was Ford Aerospace. The Martin Marietta study team became cognizant of a study, being conducted for Lewis Research Center, to examine potential designs for commercial payloads to be attached to a commercially operated geostationary earth orbiting (GEO) platform, available in the late 1990s. Both the GEO platform and the potential attached payloads are intended to be operated by commercial sources. Following initial discussions, it became clear that Ford's principal servicing interest was to determine whether to configure the commercial payloads for extended life or design for servicing.

Ford's primary concern related to the question of whether the capability to conduct retrofit operations, to accommodate new operational or technological improvements into existing payloads, would exist in the late 1990s. Ford believes that for communication payloads, for example, user coverage patterns will change, requiring smaller beamwidths. This in turn, will require new feed assemblies and changeout of wave guide interconnects. They also envision higher power amplifiers and the need to replace these onorbit. Ford expressed the need for data on design criteria for servicing and the need for servicing cost estimates as data for cost tradeoffs to determine whether to configure for servicing.

The Radio Corporation of America (RCA) is also conducting a study for LeRC on potential designs for commercial geostationary payloads. Following discussions with RCA, we agreed that their primary servicing interest related to determining the impact of servicing capability on payload design concepts.

Table 6.1-1 Commercial Satellite Servicing Assessment - Contacts

| FIRM | COMMERCIAL INTEREST |
|---|---|
| FORD AEROSPACE | COMMERCIAL GEO COMMUNICATIONS PLATFORM, COMMERCIAL GEO PAYLOAD DEFINITION |
| JOHN DEERE & CO | SPACE IRON PROCESSING |
| LOCKHEED MISSILE & SPACE CORPORATION | COMMERCIAL GEO COMMUNICATIONS PLATFORM |
| McDONNELL DOUGLAS ASTRONAUTICS CORPORATION/ JOHNSON & JOHNSON ORTHO DIVISION | ELECTROPHORESIS OPERATIONS IN SPACE |
| MIRCOGRAVITY RESEARCH ASSOCIATES | ELECTROEPITAXIAL GROWTH OF GALIUM ARSENATE CRYSTALS |
| MINNESOTA MINING AND MANUFACTURING | ORGANIC & POLYMER CHEMISTRY |
| RADIO CORPORATION OF AMERICA | COMMERCIAL GEO PAYLOAD DEFINITION |
| WYLE LABORATORIES | COMMERCE LABORATORIES |

RCA expressed the need to understand how to design for servicing to allow them to estimate this cost. They assert that providing the capability to cost efficiently retrofit existing payloads is essential. They believe that most payloads will become obsolete at about the time expendables typically have to be replaced. Thus, an interest in designing or resupply of expendables is applicable only if the spacecraft can be designed for retrofit, and a capability exists to perform the retrofit.

The Martin Marietta assessment of this potential user's interest addresses two considerations. First, it is reasonable to project that the pace of technology development will not decrease in the future, and that servicing planners should emphasize the importance of providing retrofit and resupply servicing capabilities at the Space Station. It is also clear that spacecraft designers cannot realistically do servicing cost trades without servicing design criteria and servicing cost data.

## 6.3 Commercial Geostationary Communications Platform Definition

Ford Aerospace is also conducting a Commercial GEO Communications Platform Definition study (for Marshall Space Flight Center) for a platform to provide base support for commercial payload users. As in the case of both GEO payload design studies, the principal GEO platform servicing interest is related to the question of whether to configure the platform for long life or to design it for servicing.

Ford expressed concern over whether the platform could be serviced in the late 1990s. They clearly see the benefits of being able to resupply expendables, such as fluids and batteries, and have maintenance and repair operations performed on the GEO platform. They expressed concern over the feasibility of receiving cost efficient servicing at GEO, and having to bear some portion of the cost of developing and operating OMV/OTV, and automated, intelligent front ends.

The Martin Marietta assessment of this potential user's interest is as follows. It is genuinely difficult to conduct trades considering servicing, when the essential cost data elements, are currently unavailable. Until that cost and servicing availability data has been developed, it will be difficult for commercial users to configure for servicing.

## 6.4 Electrophoresis Operations In Space

In the case of many of the concepts which have been advanced to date in the field of space manufacturing, neither the market economics nor the technological approaches have as yet been fully validated. In fact, few of these has matured to the point of flight demonstration. One is the Electrophoresis Operations in Space (EOS) program, which represents a Joint Endeavor Agreement between NASA and the McDonnell Douglas Astronautics Company (MDAC) and its teammate, the Ortho Division of Johnson and Johnson. The EOS team has conducted 5 STS experiments and is planning for operations both on free flying spacecraft/platforms and for operations at the Space Station.

The Martin Marietta study team communicated with McDonnell Douglas and found their servicing concerns to be much more specific than others due to the maturity of program planning. For operations on the Space Station, they are trying to understand how very large replacement modules (10 feet long, 12,000 pounds), can efficiently be transported to the Space Station. They are looking at shared flights with a logistics module. MDAC is also concerned with the large power service support requirements imposed on Space Station by EOS operations. They are also examining design criteria for resupply, for accommodation needs for module storage at Space Station, and, of course, for the cost of these services. The free flyer operations questions are similar in nature. One additional question was related to the availability of OMVs for expansion of module delivery and retrieval operations at an increasing number of free flying materials processing platforms.

The study team's assessment is that servicing interest of this customer is high. MDAC is planning to conduct servicing at and from the Space Station. The servicing needs are clear for the EOS program. It could serve as an excellent model for customer accommodations requirements on the Space Station, and as an initial user for some of the OMV front end kits.

## 6.5 Space Production of Electronic Microchips

The Microgravity Research Associates (MRA) organization was queried regarding status of plans for space production of microchips. They are currently conducting STS flight experiments and have a seven flight JEA presently with NASA to continue process experimentation.

When and if they progress to platform operations, they anticipate a harvest frequency of between 30-90 days, and would plan to piggy back on STS flights. At a Space Station, harvest frequency could be patterned on STS flight schedules and raw and processed materials would be delivered and returned with STS.

The study team assessment for this commercial space processing venture is that planning for production in space is at an early stage, but servicing requirements are being considered at this time by MRS, and will exist as the technology and operations mature.

## 6.6 Miscellaneous Potential Commercial Users

The data necessary to assess servicing interest for other commercial users was not available, primarily due to the expected lack of maturity in most space processing ventures. Conversation with John Deere space commercialization managers revealed that they were considering space for experimentation uses only. They do not plan presently to conduct space manufacturing of metals. Thus, they are not planning to employ platforms or use the Space Station, and cannot envision servicing requirements.

Conversations with Honeywell regarding plans for space factories in recognized areas of their materials processing expertise, mercury cadmium telluride crystal growth, provided a similar result. They have not proceeded to the point where space manufacturing operations offer clear commercial promise. Thus, they have not, as yet, evaluated the need for servicing.

## 7.0 SUMMARY OF STUDY CONCLUSIONS

The MSFC Satellite Servicing study, conducted over the past two years by Martin Marietta has supported development and refinement of the satellite servicing needs at Space Station. Specifically, study results were periodically presented to the Space Station Concept Development Group(s), and to the Satellite Servicing sub-group.

Study conclusions for Phase 2 are presented below:

a. The five TDMs selected and defined during Phase 2, if implemented, would demonstrate the highest priority servicing capabilities required at the early Space Station. In addition, these same five TDMs would demonstrate over 50% of the generally accepted servicing tasks identified during Phase 1&2 for satellite servicing.

b. The selection of specific operational or planned missions, such as AXAF and LDR, and the use of existing (MMU, EVA) and planned servicing support elements (OMV/OTV), significantly increased the clarity of Space Station servicing requirements/accommodation needs definition.

c. The TDM detailed definition efforts, including functional and operational analyses, have demonstrated the feasibility of conducting even the most complex of tasks at the Space Station. This study task also identified the most challenging of these tasks, including onorbit assembly of adaptive mirror segments, enabling a proper focus on technology development needs.

d. The identification of servicing technology development requirements will support planning for Space Station satellite servicing technology initiatives presently under consideration.

e. The STS will provide a vital link in validating servicing technology, Space Station servicing elements and servicing support equipment. Planning for servicing should include considerations for STS flight experiments.

f. The performance of TDM operational analyses has revealed a growing list of standard STS servicing tools and equipment being developed for planned missions. A high percentage of these and follow-on developments, can be transitioned to and used at Space Station.

g. Servicing cost analyses continue to support the concept that the total cost of initial servicing demonstrations (TDMs) can be reduced by using existing or planned satellite systems - GRO, ST, AXAF, LDR.

h. The assessment of commercial servicing interest resulted in a firm conviction that most planners were considering at least one aspect of servicing. There were specific questions relative to availability and cost of servicing. Potential users should be assured that their current questions and concerns are being or will be addressed in a timely manner. This can only stimulate continuing interest and support for servicing at and from the Space Station.

# APPENDIX A
# COMMON ACTIVITY SEQUENCES

Table A-OMV preparation for flight

| Event | Time | Elapsed Time |
|---|---|---|
| Man and activate SSMCS systems and console | 15 min | 0 + 15 |
| Checkout RMS control system/console | 5 min | 0 + 20 |
| Checkout OMV control system/console: checkout/evaluate/verify OMV operability and subsystems | 30 min | 0 + 50 |
| Checkout OMV ground control system/console | 30 min Parallel | 0 + 50 |
| Move RMS to OMV berthing port | 20 min | 1 + 10 |
| Latch onto OMV with RMS: grapple and rigidize/release OMV from berthing port | 5 min | 1 + 15 |
| Move OMV to cold gas launch area | 15 min | 1 + 30 |
| Berth OMV to launch site | 5 min | 1 + 35 |
| Check out OMV propulsion system: Do not fire thrusters | 15 min | 1 + 50 |
| Activate OMV SS control system | 5 min | 1 + 55 |
| Release OMV from RMS | 5 min | 2 + 00 |
| Move RMS clear of launch site | 15 min | 2 + 15 |
| Cold gas thrust OMV 2000 away from SS | 20 min | 2 + 35 |
| OMV conducts contamination monitoring during cold gas transfer | 20 min | 2 + 35 |
| Orient OMV toward desired flight track:<br>• Receive target state<br>• Vector/receive OMV state<br>• Vector/compute orbit<br>• Adjust maneuver | 5 min | 2 + 40 |
| Check out OMV propulsion system: Low power thrust | 5 min | 2 + 45 |

Table A-OMV preparation for flight (cont'd)

| Event | Time | Elapsed Time |
|---|---|---|
| Switch control of OMV from SS to ground control/launch OMV to desired orbit | 1 min | 2 + 46 |
| Deactivate SS RMS system | 1 min | 2 + 47 |
| Deactivate SS OMV control system | 1 min | 2 + 47 |

Table B-OMV transit, rendezvous, dock

| Event | Time | Elapsed Time |
|---|---|---|
| OMV transits to desired orbit | TBD | N/A |
| OMV arrives in orbit 2000' ahead of target | | |
| Determine OMV to target range & range rate<br>• GPS update of OMV state vector<br>• Calculate relative state vector using on-board calculated target state vector | 40 sec | |
| Initiate automatic station-keeping with target<br>• Continue GPS updates every 6 seconds<br>• Execute required RCS correction burns | 1 sec | 0 + 01 |
| Initiate LVLH hold mode: Acquire horizon sensor readings<br>• Update OMV attitude reference | 30 sec | 0 + 01 |
| Establish video data link:<br>• Establish TRDS link<br>• Camera 1 on<br>• Video Processor on<br>• Select video search frame rate (5 frame/sec) | 10 sec | 0 + 02 |
| Verify OMV subsystem performance:<br>• Video Comm, command link<br>• RCS propulsion<br>• Extend end effector<br>• Safe OMV main engines<br>• Verify eng. data in limits | 10 sec | 0 + 02 |
| Search for and acquire target:<br>• Visual examination of video screen until target detected | 4 min | 0 + 07 |
| Prepare to close<br>• Center target in screen<br>• Select motion detection frame rate (1 frame/sec)<br>• Determine R and $\dot{R}$<br>• Apply + X$\Delta$V to close | 40 sec | 0 + 07 |

Table B-OMV transit, rendezvous, dock (cont'd)

| Event | Time | Elapsed Time |
|---|---|---|
| Video close from 2000' $\overline{V}$:<br>• Apply Y and Z thrust to maintain target centered<br>• Brake as closing velocity is sensed<br>• Brake to stop at -200' $\overline{V}$<br>• Turn on camera 2 | 13 min | 0 + 20 |
| Perform transition maneuver to move around radius vector at a 200' standoff to docking probe axis<br>• Apply initial translation thrust<br>• Maintain target distance with +X thrust<br>• Visually inspect target distance with +X thrust<br>• Visually inspect target, verify cooperative conditions<br>• Apply braking thrust to align on docking probe axis<br>• Select Prox Ops frame rate (5 frames/sec) | 5 min | 0 + 25 |
| Close to 40' standoff point:<br>• Activate cold gas RCS<br>• Apply +X thrust<br>• Brake as closing velocity is sensed<br>• Turn on OMV docking light at 100'<br>• Brake to standoff at 40' | 6 min | 0 +31 |
| Inspect and configure target<br>• Operate pan tilt search w/camera 2<br>• Verify docking probe system and approach path<br>• Configure target for docking<br>• Roll to target alignment<br>• Verify proper docking orientation<br>• Turn on power to docking mechanism<br>• Flight director approves go for dock (lighting, TDRSS coverage adequate) | 3 min | 0 + 34 |
| Close from 40' to docking envelope<br>• Apply +X thrust to close<br>• Apply thrust as necessary to align target in video screen reticles<br>• Hold position for 15 sec. once target ready for capture | 6 min | 0 + 40 |

Table B-OMV transit, rendezvous, dock (cont'd)

| Event | Time | Elapsed Time |
|---|---|---|
| Target capture and hard dock<br>• Close end effector snares<br>• Retract snares for rigid dock<br>Retract end effector<br>• Engages hard dock latches<br>• Turn off power to docking mechanism | 2 min | 0 + 42 |

Table C-OMV returns/berths to Space Station

| Event | Time | Elapsed Time |
|---|---|---|
| Configure OMV for orbit adjust maneuver | 5 min | 0 + 05 |
| Compute orbit adjust maneuver | 5 min | 0 + 10 |
| Orient for orbit adjust burn | 5 min | 0 + 15 |
| Transit to Space Station: Take station 2000' away from SS | 60 min | 1 + 15 |
| Check out RMS control system/console | 5 min | 1 + 20 |
| Check out SS OMV control system/console | 5 min | 1 + 20 |
| Check out fueling depot control system/console | 15 min | 1 + 40 |
| Switch control of OMV from ground control to SS | 1 sec | 1 + 40 |
| Move RMS to OMV berthing port | 14 min | 1 + 55 |
| Deactivate OMV main engines | 1 sec | 1 + 55 |
| Cold gas thrust OMV to berthing port | 20 min | 2 + 15 |
| OMV monitors contamination surrounding SS | 20 min parallel | 2 + 15 |
| RMS latches onto OMV | 5 min | 2 + 20 |
| RMS moves/berths OMV to fuel depot | 30 min | 2 + 50 |
| RMS connects defueling lines to OMV | 30 min | 3 + 20 |
| Defuel OMV | 60 min | 4 + 20 |
| RMS disconnects defueling lines/stow lines moves/berths OMV to servicing facility for refurbishment | 5 min | 4 + 25 |

Table D-OMV refurbishment

| Event | Time | Elapsed Time |
|---|---|---|
| RMS grapples returning OMV and berths it to the fuel depot | 30 min | 0 + 30 |
| RMS connects required umbilicals to OMV/OMV defueled | 90 min | 2 + 00 |
| RMS disconnects umbilicals and moves/berths OMV to servicing facility rotatable carousel | 30 min | 2 + 30 |
| Refurbish OMV (routine-extended)<br>• connect test equipment umbilicals to OMV test ports using servicing facility RMS<br>• Visually inspect OMV outer structure using TV camera<br>• Replace OMV modules failing test and modules scheduled for replacement (EVA required) | 3-12 hrs | |
| RMS moves OMV to fueling depot | 30 min | 3 + 00 (+ refurbishment) |
| RMS connect required umbilicals to OMV/OMV fueled | 90 min | 4 + 30 (+ refurbishment) |
| RMS disconnects umbilicals and moves/berths OMV to OMV berthing port | 30 min | 5 + 00 (+ refurbishment) |

Table E-EVA preparation

| Event | Time | Elapsed Time |
|---|---|---|
| 2 astronauts prepare for EVA | 2 + 30 | 2 + 30<br>+ prebreathe |

- Open airlock hatch
- Transfer EVA equipment into airlock if equipment is not stowed there
- Prepare EMU's for donning
- Power up EMU's
- Perform communications checks with SS
- Checkout primary and secondary oxygen
- Check battery charge
- Power down EMU's
- Don liquid cooling and ventilation garments and biomed
- Power up EMU's
- Configure airlock panels ($O_2$, comm, water)
- Don EMU's, check communications
- Purge EMU of nitrogen
- Prebreathe in EMU (TBD)
- Egress EMU mounts
- Close inner hatch
- Depress airlock to 5 psi
- Perform EMU leak check
- Transfer power to battery
- Disconnect umbilicals
- Place $O_2$ actuator in EVA mode
- Secondary oxygen package on line
- Depress airlock to vacuum
- Open outer hatch
- Activate sublimintors

Table F-Transferring two astronauts from airlock to servicing facility and back

| Event | Time | Elapsed Time |
|---|---|---|
| Move astronauts from airlock to servicing facility | | |
| EVA #1 transits airlock; mounts MFR | 1 min | 0 + 01 |
| RMS moves to servicing facility | 10 min | 0 + 11 |
| EVA #1 enters servicing facility | 1 min | 0 + 12 |
| RMS moves to airlock | 10 min | 0 + 22 |
| EVA #2 transits airlock; mounts MFR | 1 min | 0 + 23 |
| RMS moves to servicing facility | 10 min | 0 + 33 |
| EVA #2 enters servicing facility | 1 min | 0 + 34 |
| Move astronauts from servicing facility to airlock | | |
| Move RMS to servicing facility | 10 min | 0 + 10 |
| EVA #2 mounts MFR | 1 min | 0 + 11 |
| RMS moves to airlock | 10 min | 0 + 21 |
| EVA #2 enters airlock | 1 min | 0 + 22 |
| RMS moves to servicing facility | 10 min | 0 + 32 |
| EVA #1 mounts MFR | 1 min | 0 + 33 |
| RMS moves to airlock | 10 min | 0 + 43 |
| EVA #1 enters airlock | 1 min | 0 + 44 |
| Deactivate RMS console | 1 min | 0 + 45 |

Table G-Typical EVA day

| Event | Time<br>6 EVA hrs/man | Elapsed Time<br>6 EVA hrs/man |
|---|---|---|
| Disconnect/remove/replace science instrument modules failing component test and those scheduled for replacement | | |

EVA # 1 opens aft end hinged door exposing science instrument modules

- Disconnect 1st faulty instrument module
- EVA #1 tells EVA #2 which module is being removed
- EVA #2 removes replacement module from resupply carousel
- Remove 1st faulty instrument module
- Move 1st faulty instrument module with EVA #1 and servicing facility RMS (SFRMS) to EVA #2
- Give 1st faulty instrument module to EVA #2
- EVA #2 receives 1st faulty instrument module
- EVA #2 places faulty instrument in ORU resupply carousel
- EVA #2 gives EVA #1 replacement module
- EVA #1 returns to aft end of satellite
- EVA #1 replaces and connects replacement module in satellite

Repeat for each faulty/scheduled replacement instrument

Table H-Post EVA activity

| Event | Time | Elapsed Time |
|---|---|---|
| Reentering Space Station | 2 hrs | 2 + 00 |
| • Ingress airlock | | |
| • Deactivate subliminators | | |
| • Place $O_2$ actuator in "press" | | |
| • Secondary oxygen package offline | | |
| • Prepress airlock to 5 psi | | |
| • Connect umbilicals | | |
| • Transfer power to SS | | |
| • Place $O_2$ actuator in "IV" soft suit | | |
| • Repress airlock to cabin pressure | | |
| • Doff EMU's | | |
| • Perform recharge | | |
| – Replace airlock to cabin pressure | | |
| – Replace battery | | |
| – Recharge $O_2$ | | |
| – Recharge $H_2O$ (current EMU) | | |
| • Stow EVA equipment | | |
| • Open inner airlock hatch | | |
| Post EVA equipment maintenance | | |
| Current EMU | 30 min | 2 + 30 |
| • Perform EMU leak checks | | |
| • Clean spacesuit assembly | | |
| Extended life EMU | 90 min + Repair | 4 + 00 |
| • Perform EMU leak checks | | |
| • Clean spacesuit assembly | | |
| • Clean liquid and cooling garment | | |
| • Readjust life support system sensors (if necessary) | | |
| Checkout caution and warning system | | |
| • Checkout of components and replacement (when necessary) | | |
| • Recharge, check regenative thermal control and $CO_2$ systems | | |
| • Check, secondary oxygen package, display and control module | | |
| • Check, replace worn spacesuit assembly components | | |

Table I-Transfer stack buildup

| Event | Time | Elapsed Time |
|---|---|---|
| Man and activate SSMCC systems and consoles | 15 min | 0 + 15 |
| Checkout OMV ground control system/console | 5 min | 0 + 15 |
| Check intelligent servicer (IS) ground ground control system/console | 5 min parallel | 0 + 15 |
| Checkout OMV SS control system /console | 5 min | 0 + 20 |
| Checkout RMS control system/console | 5 min | 0 + 25 |
| Checkout fueling system/console | 5 min | 0 + 30 |
| Conduct fuel test/sample | 15 min | 0 + 45 |
| Move RMS to storage facility | 15 min | 0 + 45 |
| RMS latches onto IS | 5 min | 0 + 50 |
| RMS moves to servicing facility and attaches IS to servicing facility carousel | 30 min | 1 + 20 |
| RMS releases IS/RMS connects data umbilical to IS | 15 min | 1 + 35 |
| Checkout IS system | 1 hr | 2 + 35 |
| Ground control loads IS computer data base with all updated diagnostic and alternative recovery algorithms | 1 hr | 2 + 35 |
| RMS moves to OMV2 berthing port | 15 min parallel | 3 + 35 |
| RMS latches onto OMV2/OMV2 released from berthing port | 5 min | 3 + 35 |
| RMS moves to cold gas launch area/berths OMV2/RMS releases OMV2 | 20 min | 3 + 35 |
| RMS moves to OMV1 berthing port | 15 min | 3 + 35 |
| RMS moves to servicing facility and attaches OMV1 to IS/RMS releases OMV1 | 30 min | 3 + 35 |

Table I-Transfer stack buildup (cont'd)

| Event | Time | Elapsed Time |
|---|---|---|
| RMS moves to OTV storage facility | 15 min | 3 + 35 |
| RMS latches onto OTV/OTV released from berthing port | 5 min | 3 + 35 |
| RMS pulls OTV from storage facility | 30 min partially parallel | 3 + 55 |
| RMS moves to servicing facility and attaches OTV to OMV1 and IS OTV/OMV1/IS hookup now defined as Transfer Stack | 30 min | 4 + 25 |
| RMS latches onto transfer stack | 5 min | 4 + 30 |
| RMS moves to OTV fueling depot/transfer stack berthed to fuel depot | 30 min | 5 + 00 |
| RMS releases transfer stack/connect fueling umbilicals to OTV/configure OTV propulsion system for fuel transfer | 30 min | 5 + 30 |
| Childown main propellant tank/lines | 2 hr | 7 + 30 |
| Fuel OTV/monitor contamination, propellant pressurant levels, temperatures | 3 hr | 10 + 30 |
| RMS disconnects fueling umbilicals from OTV | 30 min | 11 + 00 |
| RMS latches onto transfer stack/transfer stack released from OTV fuel depot berthing | 5 min | 11 + 05 |
| RMS moves transfer stack to cold gas launch area and berths transfer stack to OMV2 | 45 min | 11 + 50 |
| RMS releases transfer stack and moves clear of launch area | 15 min | 12 + 05 |
| OMV2 cold gases transfer 2000' away from SS | 20 min | 12 + 25 |
| OMV2 monitors contamination during cold gas transfer | 20 min parallel | 12 + 25 |

Table I-Transfer stack buildup (cont'd)

| Event | Time | Elapsed Time |
|---|---|---|
| OMV2 releases transfer stack/returns to SS | 30 min | 12 + 55 |
| RMS moves to OMV2 berthing port | 15 min | 13 + 10 |
| RMS latches onto OMV2/RMS moves OMV2 to OMV fueling depot | 20 min | 13 + 30 |
| RMS berths OMV2 to OMV fueling depot/connect defueling lines | 20 min | 13 + 50 |
| Defuel OMV2 | 1 hr | 14 + 50 |
| OTV extends engine nozzles (if retracted) extend all necessary equipment for flight | 5 min | 14 + 50 |
| OTV orients towards desired flight track | 1 min | 14 + 50 |
| Switch OTV control to ground control | 1 sec | 14 + 50 |
| OTV transfers OMV1/IS to GEO | 6 hr | N/A |
| RMS disconnects defueling lines | 15 min | 15 + 05 |
| RMS latches onto OMV2/release OMV2 from OMV fueling depot | 5 min | 15 + 10 |
| RMS moves OMV2 to servicing facility for refurbishment | 20 min | 15 + 30 |
| RMS berths OMV2/releases OMV2 | 10 min | 15 + 40 |
| Deactivate SS OMV control stations | 1 min | 15 + 41 |
| Deactivates SS RMS control station | 1 min | 15 + 42 |
| Refurbish OMV2 (as necessary) | 3-12 hrs | N/A |